LIFE LEMA's

TECHNICAL SYNTHESIS REPORT

By LIFE LEMA Team

February 2020

LIFE15 ENV/ES/000252

Table of content

Introduction

Marine litter is one of the most important environmental challenges that humanity faces, as it affects all countries to a greater or lesser extent, regardless of where the waste comes from. Marine litter is defined as being any non-natural persistent (manufactured) solid, which has been thrown away, dumped or abandoned in marine and/or coastal habitats. Marine litter is made up of numerous materials, although plastic is the most commonly-found material. As this is mainly waste made up of synthetic materials, and as a result, with extremely low natural degradation rates, nature is unable to assimilate anthropic waste at the rate that it enters the oceans. Subsequently, we are witnessing an unprecedented process of waste accumulation in the sea. However, the impact of marine litter on organisms and ecosystems is wide-ranging, examples are the impacts caused by the ingestion and entanglement; in the case of microplastics, they may even lead to having a physiological impact, according to various studies.

The Bay of Biscay is no exception to the world-wide problems associated with marine litter. Being aware of this, and in order to be able to progress in the struggle against marine litter, the LIFE LEMA Project was launched in September 2016 thanks to the funding received from the European LIFE programme for the Environment and Resources Efficiency.

The Project aimed at defining a holistic strategy for managing floating marine litter (FML) to guide the local authorities, who are responsible for protecting the seas and coasts, in selecting the most sustainable approach for collecting FML and preventing it from having an impact on the environment.

1 Objective

The aim of this document is to provide a summary of the technical knowledge gained during the execution of LIFE LEMA, encouraging the dissemination of the information and the replication of protocols defined by the project in order to support local authorities in their management actions for tackling FML. Section 2 of the present document describes the main methodologies deployed; Section 3 provides a synthesis of main project results; and Section 4 summarizes conclusions and perspectives.

2 Methodologies and techniques

2.1 Collection of Floating Marine Litter

During LIFE LEMA, three different complementary efforts were investigated, demonstrated and assessed to collect FML from the water environment (Figure 1):

- Collection at sea with fishing and cleaning vessels,
- Collection on beaches with cleaning machines or manually,
- Collection in rivers with an interception barrier.

The detailed monitoring of these collection operations provided crucial knowledge about FML abundance and the related space-time variability. Collection operations had, thus, the double benefit of removing litter from the environment and feeding the scientific developments with relevant data.

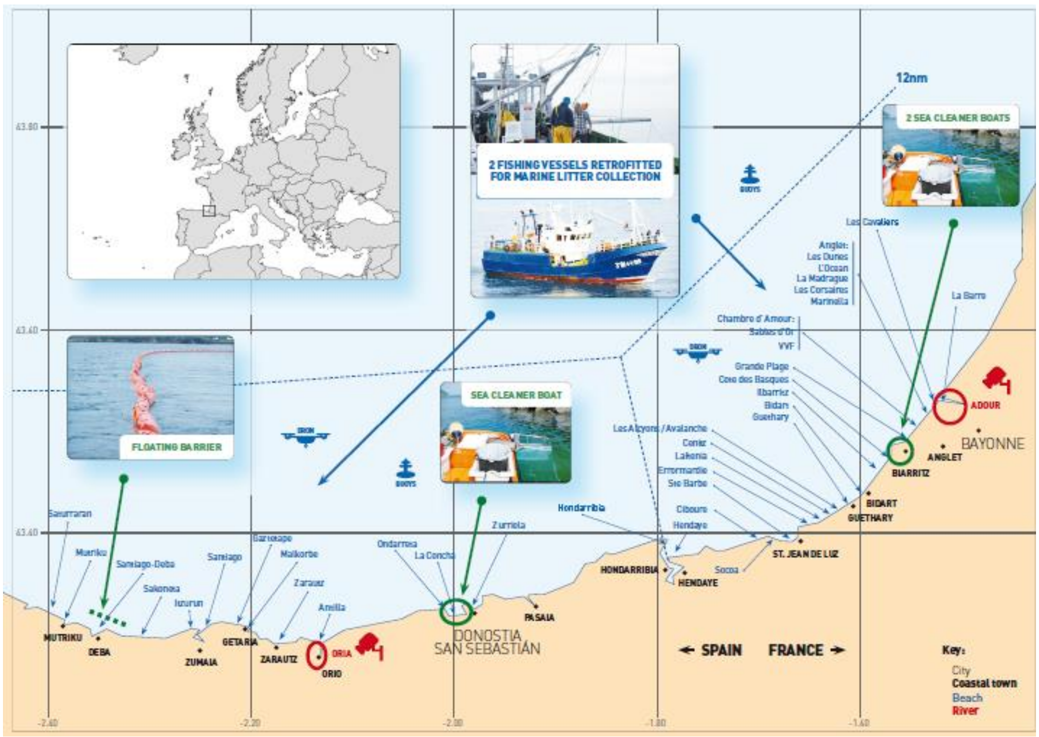

Figure 1 : LIFE LEMA project area, collection effort distribution and new technologies deployment

2.1.1 Collection at sea with fishing and cleaning vessels

Two fishing vessels and two sea cleaning vessels (from now own the "LEMA vessels") were subcontracted during the project to undertake the FML collection (Figure 2). The purpose of involving fishing vessels was twofold: (i) to study the possibility of diversifying the fishing activity by engaging them in the active fishing for litter during their low economic fishing activities (i.e. active retrieval of marine litter by vessels that have been paid to perform this activity (UNEP(DEPI)/MED, 2016), and (ii) to assess the efficiency and effectiveness of the active versus passive fishing for litter.

Figure 2 : LEMA vessels involved in the active fishing for litter: top the fishing vessels Miren Argia (A) and the Itsas Belhara (B); and bottom the BAB Subaquatique (C) and the Uhaina (D)

a) Macrolitter collection by LEMA vessels

The fishing vessels *Miren Argia* and *Itsas Belhara* (Spanish and French respectively) worked in coastal waters of Gipuzkoa province (Spain) and Labourd region (France), respectively. They covered the area comprised between 300 m to 3 nautical miles off the coast approximately; except for the *Miren Argia*, who extended the working area to 6 nautical miles in 2017. The sea cleaning vessels *Uhaina* and *BAB Subaquatique* carried their activity in the bathing areas, rocky shores and in coastal waters of the municipality of Biarritz (France) (Figure 2). While all three French vessels had years of experience collecting FML, no experienced fishing vessel was found in the Basque-Spanish region before LIFE LEMA started. Therefore, to select an appropriate vessel to operate in Spain, a socio-economic analysis was performed on the local fishing fleet. Artisanal fishing fleet was nominated as the most appropriate segment based on their fishing season, fishing areas, fuel consumption, and potential diversification season, being the summer one of the target seasons regarding marine litter for local authorities (more information in Deliverable DB1.1 "Selection of technology and target fleet"). Once the target fleet was defined, the local artisanal shipowners were invited to participate in the tender that led to the final selection of the fourth LEMA vessel, the *Miren Argia*.

The crews of all the LEMA vessels were trained to follow the same collection methodology. Nonetheless, the fishing gear employed for the collection differed slightly amongst the participant vessels, mainly due to the fact that the gear had to be adapted to the type and size of the vessels. In general terms, the gear consisted of an artisanal net adapted for FML collection, featuring a rectangular metallic frame and a nylon net with a 20 mm (in the case of the fishing vessels), or 2-7 mm mesh size (in the case of the sea-cleaning vessels). The nets covered the first 30-50 cm from the sea surface, depending on the sea conditions. The collection was carried out at a speed ≤ 3 knots in all vessels. The nets were complemented with dipnets and hooks that the fishers used to collect single litter. These gears showed to be effective and accepted by the crew of the LEMA vessels, due to their good manoeuvrability (on board and in the sea), low maintenance costs and durability. The gears employed are shown in Figures 3-4.

The collected FML was stored in big bags onboard the vessels (Figure 3C). Approximately weekly, the big bags were landed in the vessels' main ports (Pasaia, Saint Jean de Luz and Biarritz). The fishers weighted the big bags (Figures 3D and 3E) and reported the fishing activity and the collected amount in the LEMA tool (explained in Section 2.3).

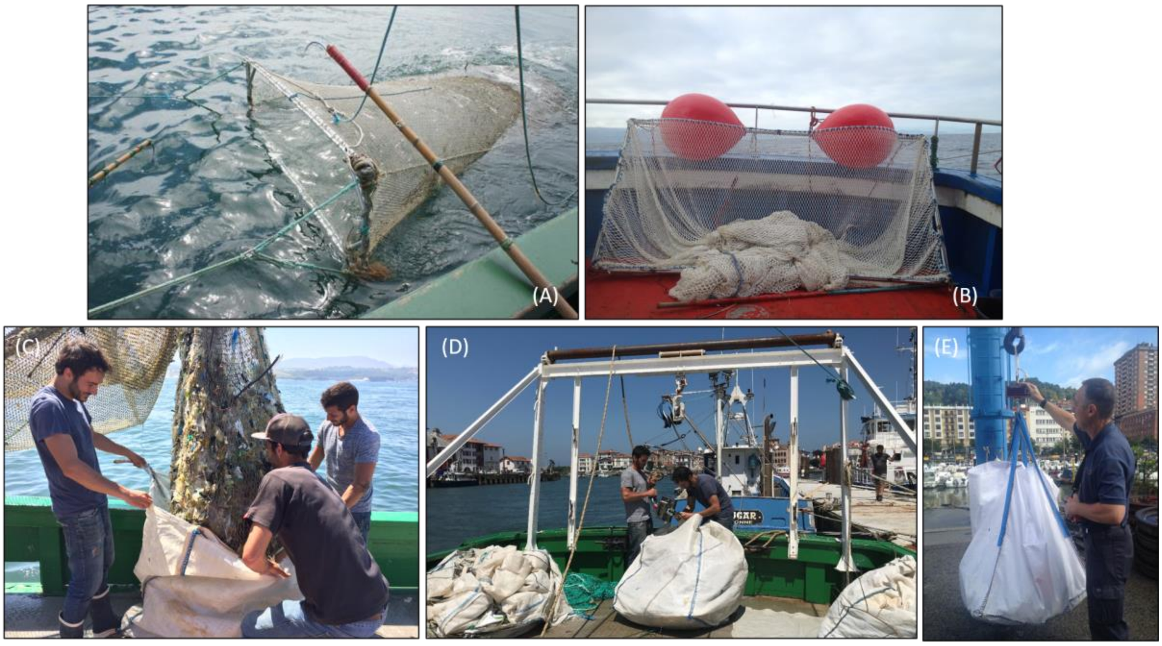

Figure 3 : FML collection gears used by the LEMA fishing vessels (A - Itsas Belhara, B - Miren Argia), storing FML in big bags onboard (C- example of the Itsas Belhara), and the weighting procedure onboard (D - Itsas Belhara), or in port (E - Miren Argia).

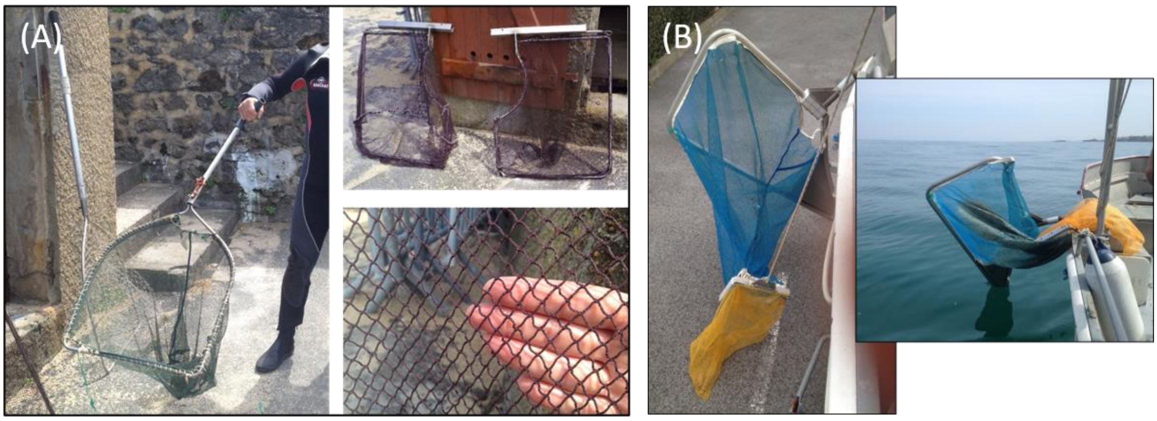

Figure 4 : Gears employed by the BAB Subaquatique (A) and the Uhaina (B) sea-cleaning vessels for collecting FML

The LIFE LEMA vessels were equipped with a vessel monitoring system named the SIMUL (developed by AZTI) that served to monitor the fuel consumption of the vessel as well as to geolocate the vessels' activity (Figure 5). This information not only served to study marine litter accumulation patterns but also provided invaluable information to define collection strategies (further discussed in the LEMA tool section). The protocol carried out is detailed in the "Deliverable DB3.1 Energy audit of vessels including the assessment of energy saving measures".

Figure 5 : Energy and vessel monitoring device onboard the Itsas Belhara

Given that active fishing for litter was unprecedented in Spain, a new administrative procedure had to be established by the Harbour Masters of Pasaia and Bilbao (Spain) to grant authorisation for the active fishing for litter activities. The flowchart of the procedure, authorisation and certifications required are detailed in Figure 6. As defined by the procedure, any shipower willing to engage with active Fishing for Litter activities has to provide a report describing the active fishing for litter strategy (fishing zones, period, means employed…) with different authorisations and certifications to the local Harbour Master's Office (who is the one granting the final authorisation). Such authorisation and certifications are meant to guarantee that the activity will have no impact on the environment, fishing activity and waste management issues. Also, if the vessel requires any retrofitting to be able to engage with active fishing for litter activities. the retrofitting works will need to be approved by a naval architect, who will have to report on that. The whole process may take several months.

In contrast, in France no additional administrative procedure was required apart from reporting the amount of litter caught and landed in their logbooks.

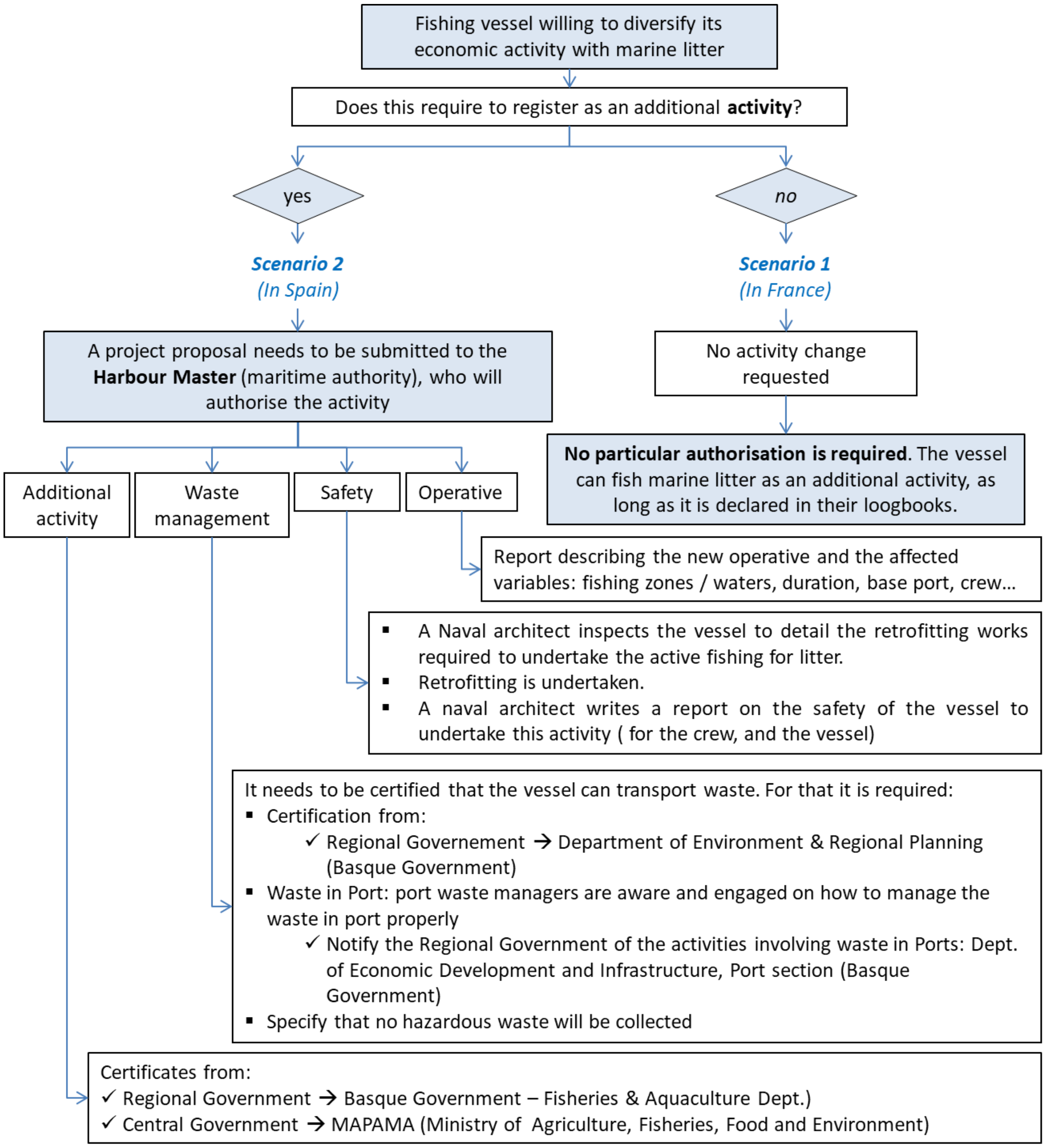

Figure 6 : Flowchart of the steps and critical factors involved in obtaining of the authorisation for active fishing for litter activities in Spain (example set for Basque fishing vessels)

b) Microplastic survey

The microplastic surveys of LIFE LEMA was performed during the years 2017 and 2018. In 2017, the survey was carried along the Gipuzkoa (SP) coastline (Figure 6, blue points) onboard the fishing vessels *Miren Argia*. The sampling stations were strategically located at 2, 4, and 6 nautical miles from the coast. In each location, one microplastic sample was taken. To identify any temporal trend, the sampling was repeated once each month for September, October and November 2017. This resulted in a total of 99 samples for the Gipuzkoa coastline. Following the same protocol, in 2018, the microplastic samples were collected along the Labourd (FR) coastline (Figure 6, white points) onboard the fishing vessel *Itsas Belhara*. The sampling effort in 2018 (33 samples) focused on the summer months (May to September); and consisted in the sampling of 7 stations (except from May with 6 stations sampled). In total, 132 microplastic samples were collected in the coastal water of the Basque Country during these 2 years.

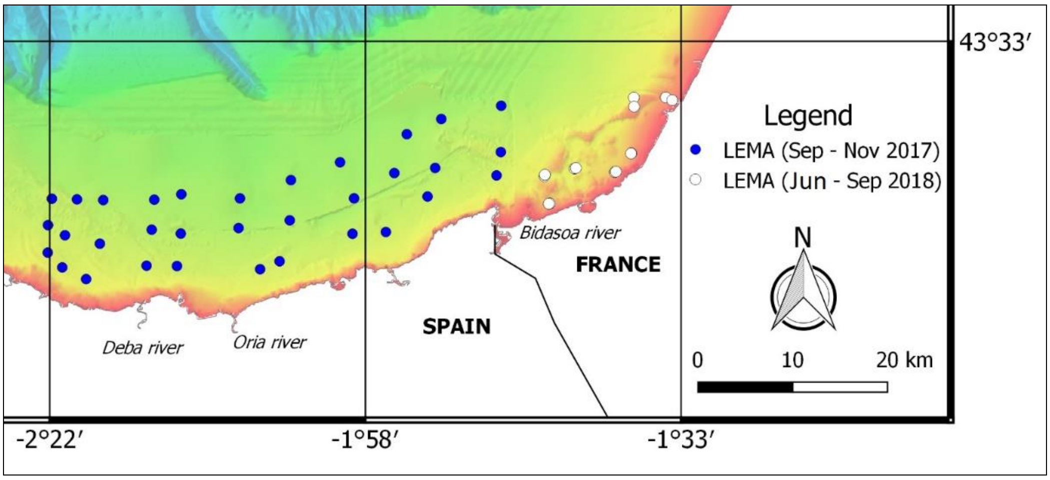

Figure 7: Sampling positions from 2017 and 2018 Life LEMA microplastic surveys

The protocol followed on board was the one used in the literature by most of the research teams working with microplastic pollution (Cozar et al., 2014; Ruiz-Orejón et al., 2018). A neuston net with a 500-mesh size fixed to a rectangle frame, 100 cm x 50 cm opening, was employed for the sampling. The net was towed in each station for 15 minutes with at a vessel speed of 2-3 knots. As an average, the distance sampled was 1.4 km. During the tow, the net collected water from the first 35 cm of the sea surface. The initial and final position of the samplings were recorded in order to compute the exact distance sampled (assumed to be linear). The net had a flowmeter attached to the frame in order to provide the estimate of the water filtered during the sampling. After the tow, filtered material was transferred to a coded plastic bag, stored and frozen at -18 degrees until analysis.

Once at lab, after being defrosted, the samples were rinsed with tap water and filtered using a filter with a mesh size of 500 µm. Subsequently, the microplastic items were extracted from the samples by the aid of a binocular. However, for those samples containing a significant amount of organic matter (plankton, microalgae or little branches), a pre-treatment was applied to reduce the organic load of the samples, which consisted of mixing the samples with Sodium Hydroxyde (5 M) and then subjecting the treated sample to sonication.

Microplastic results obtained from the LIFE LEMA campaign were recalculated according to wind and wave data by applying Kukulka and colleagues' model (Kukulka et al., 2012) in order to consider the mixing of plastic particles in the water column.

2.1.2 Collecting marine litter on beaches

Beaches are the final destination of a significant part of the litter after their journey in the sea. Large accumulations can be observed onshore, which threaten the environment and beach ecosystems, as well as public health and safety. Another component of FML interception is, therefore, the collection on beaches.

As part of LIFE LEMA, beach cleaning operations were conducted, assessed and monitor on the pilot site of Biarritz (Figure 8). Two types of collect operations were conducted:

- Daily collect all year long with cleaning machines,
- Manual daily collect during the summer season.

Figure 8 : Beach cleaning operations participating in LIFE LEMA initiative on Biarritz pilot site

Both of these efforts were monitored in detail during the project, while Biarritz cleaning services were involved in the testing and evaluation of new tools developed as part of LIFE LEMA. The related dataset and feedback contributed largely to improve the knowledge about marine litter dynamics, validating monitoring and modelling techniques, and assessing decision-aid tools and management strategies.

2.1.3 Collecting FML in river: barrier

Considering that a large amount of marine litter comes from land activities, and in order to learn more about the behaviour of land activities and rivers in the south-east of the Bay of Biscay, a floating barrier was placed on the River Deba (Spain).

The choice of the river Deba as the location of the floating barrier was due to the quantity and type of litter normally collected by the cleaning services on Ondarbeltz beach, located on the left bank of the mouth of the River Deba at the western end of the Gipuzkoan coastline (Figure 9).

Figure 9 : Location of the mouth of the River Deba and Ondarbeltz beach

The selection of the technology for the barrier and its location was based on a review of the literature on commercial barriers, a visit (December 2016) to an operating floating barrier located on the Nivelle River as it passes through Saint Jean de Luz (France) and a comparison with professionals on the logistics for its installation and maintenance, the compatibility of the installation with other uses and the activities carried out on the river, protection of fish fauna, etc. With all the information gathered, a preliminary study of the existing technology and the potential locations for its installation was carried out, including a SWOT analysis of the different alternatives.

The choice of artisanal barriers was based mainly on the fact that they are made from nets commonly used in fishing with buoys for flotation, which has the following advantages: low cost, high strength and retention capacity, modular and easy to install. The characteristics are as follows:

- Net material: Nylon
- Length: 40 m
- Width (depth): 0.6 m
- Mesh size: 60 mm

The floating barrier was installed on 16/3/2018 at the mouth of the River Deba (Spain) to retain the floating litter transported by the river to the sea (Figure 10).

Figure 10 : Barrier (left) installed in Deba river (right)

2.1.4 Science for citizen

Furthermore, during the 3 years of the project, in order to collect data on the general state of the coast, litter monitoring campaigns (were carried out in 3 coves of Gipuzkoa. The international OSPAR protocol (Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area) was followed for the collection/sampling of beach litter, and the subsequent characterization.

In total, 48 sampling campaigns were undertaken with the help of volunteers, which contributed to increase the citizens' involvement and interest in scientific projects and on marine litter pollution. Thanks to the characterisation work performed, it was defined that the most frequent items found were Plastic/polystyrene pieces- 2.5- 50 cm-, drink and food packages, and strings and cords. This allowed us to identify the critical source of marine litter in Basque beaches, and thus, where the effort is worth focusing in order to reduce the marine litter impacts. Also, it served to foster debate about production and consumption processes inspiring changes of habits in the society of consume.

These actions of science for citizens aimed at increasing awareness about marine litter impact and collect scientific data useful in the framework of the LIFE LEMA. The volunteering program of science for citizen was coordinated by Surfrider representing a complementary action for the project totally independent by the European funds.

The collection campaigns were carried out every season, following the outlined calendar:

- Winter: mid-December to mid-January
- Spring: April
- Summer: mid-June to mid-July
- Autumn: mid-September to mid-October

There are several benefits by create a science for citizen campaign in the framework of the data collection program:

- Gather additional data to feed the LEMA tool.
- Involve citizen in the waste management taking part directly in dataset collection and management discussion.
- Build up a critical mass around waste management and open participation.

2.2 New technologies to monitor and predict Floating Marine Litter transport and hotspots

2.2.1 Monitoring and modelling floating marine litter in LIFE LEMA

The monitoring of marine litter is of utmost importance to guarantee a good environmental status of our Seas and Oceans, as it is reflected by the Marine Strategy Framework Directive (MSFD). There are several options and tools available for the monitoring of marine litter in the different environmental compartments, i.e. beach litter, floating litter, seafloor litter, litter in biota and microlitter (Galgani et al., 2013). Although visual observation is gaining importance to detect riverine litter that ends up becoming FML thanks to the RIMMEL network (http://mcc.jrc.ec.europa.eu/dev.py?N=simple&O=394&titre_page=RIMMEL%20observation%20Network), few are the technological advances on this regard. Two promising monitoring technologies were developed and demonstrated in LIFE LEMA:

- Real Time video monitoring system for river mouths,
- Offshore FML detection from airborne systems (drones).

Complementary to monitoring, FML transport was investigated in LIFE LEMA to improve knowledge about FML pathways, sources and destination. These investigations relied on two main components:

- Surface transport observations with different types of drifting buoys,
- Numerical modelling FML dispersion based on metocean tools.

2.2.2 Detection in rivers with videometry techniques

The main objective of the work conducted was to explore the capabilities of a land-based videometrical technology in order to provide a near real time quantitative indicator of the FML released in the coastal area by a specific river. For that, the main specific actions included the installation of camera systems at pilot rivers mouth and the development of an algorithm based on image processing that allows the automatic detection of FML that passes through a certain area of the river.

Two demonstration sites were equipped with this innovative videometry monitoring system during LIFE LEMA: the Orio river mouth and the Adour estuary (see Figure 11 and Figure 12).

Figure 11: Illustrations of the Orio river video monitoring station

Figure 12 : Illustrations of the Adour river video monitoring station

The selected technological solution was based on a NIR (Near InfraRed) camera and an IR spotlight facilitating the illumination of the scene at night. The main reason for choosing an IR camera was that it theoretically enhances the contrast between the floating objects and the water, an essential factor to ensure the automatic detection.

The developed algorithm provided an automatic detection of floating litter and derived indicators and statistics. It provided a continuous, real time indication about floating litter being outflowed from the rivers toward the ocean. As part of LIFE LEMA, the detection procedure was developed and optimized in collaboration with TECNALIA (subcontractor), deployed on the two pilot sites, and the related accuracy was evaluated. Eventually, the system functioning was demonstrated in real conditions during the project demonstration time windows, i.e. during spring and summer 2018 and 2019.

2.2.3 Detection at sea from UAV images

The work conducted in LIFE LEMA focused on the adaptation of UAV system for FML detection. It aimed at assessing the feasibility of the use of a UAV-based detection system for two applications: detection of FML accumulation over given coastal areas (or patch detection and direct localization of large FML objects at sea. This work was conducted in collaboration with our subcontractor TELESPAZIO France.

For this purpose, the specific action conducted in the framework of LIFE LEMA included: (1) 3 test flights with a drone that collected images over a pilot coastal area, and (2) the development and testing of a processing algorithm to automatically detect floating objects in the collected images. The pilot area for the test was the area of influence of the Adour river plume, along the French Basque coast.

The drone solution used was a commercial drone (Figure 13), commonly available, without any specific developments. For images acquisition onboard the drone, two technologies were tested: (1) a "classical" optical RGB sensor, and (2) a multi-spectral sensor. The respective performances and advantages of both sensors were assessed for the purpose of FML detection, with the aim of identifying the most relevant solution.

Figure 13: Zenmuse Z3- matrice 100 UAV system used for the experimentations

Regarding the detection algorithm, two approaches were also tested to process the images:

- A machine learning approach, which is based on training samples to feed a model that is further applied to all the images
- A marine optics approach, which is based on water transparency to identify anomalies in water column optical properties.

Both approaches were assessed in an effort to investigate the feasibility and performances of autonomous algorithms for FML detection in images collected by a drone at sea, and provide related recommendations.

The test area for the drone mission was set to the area influenced by the Adour river plume, which is suspected to be one of the major sources of FML in the region. Regulatory conditions were strictly controlled with institutional authorizations and aerial regulations, permitting a maximum distance between the drone and the pilot around 1 km (regulation related to urbanized area). The 3 test flights were operated from the shore. The covered area focused on the northern and southern vicinity of the Adour mouth, as shown in Figure 14. Three test flights were performed from the shore and collected images:

- Flight #1: March 22, 2018
- Flight #2: April 19, 2018
- Flight #3: June 26, 2018

Figure 14 : Location of area (red) for the drone mission from the shore. Background Landsat-8 satellite image shows the turbid Adour river plume.

2.2.4 Surface transport observations with drifters

Regional and coastal ocean models have recently provided valuable information on FML behavior but the increasing need for detailed data from FML pathways requires the use of observational tools, to (i) complement the numerical investigations and (ii) to validate the simulation results and improve the quality of the transport forecasting. Floating oceanographic devices such as low-cost satellite-tracked drifting buoys have proven their effectiveness in measure sea surface circulations (Novelli et al., 2017; Laxague et al., 2018) and they have taken on new importance in the study of FML propagation in the open ocean (NOAA, 2016) but also in the estuarine and coastal areas (Meyerjürgens et al., 2019).

In the scope of LIFE LEMA project, 2 types of drifters with complementary capacities were deployed:

- Tagged wooden drifters,
- Satellite drifting buoys (GPS-tracked).

a) Wooden drifters

The wooden drifter consists of a degradable floating boat without GPS. The boats were created in close cooperation with Albaola Faktoria (http://www.albaola.com/en), who provided the wood pieces required for the boat construction for free, and local craft man). The assembling and decoration activities were performed thanks to citizens' support. Each boat was also tagged, and the information was printed on its surface by laser technology. Each boat was also coded under a specific identification number between 1 and 1,000 (see Figure 15).

Figure 15 : Process of assembling pieces performed by Jenő Kocsis (local craft man) and example of laser printing

b) Satellite drifting buoys

To complement the information provided by wooden drifters about FML destination, satellite tracked (GPS) drifters were also deployed as part of LIFE LEMA, allowing to access to detailed information about FML trajectories. Two types of sensors were uses:

- low-cost drifting buoys providing timeseries of buoy GPS locations (Figure 16) were released at river mouths and in the coastal ocean as part of different experiments to track surface transport over timescales from 1 day to several weeks;

- middle-cost sensors providing GPS locations plus measurements of water properties along the trajectory (Figure 17), were released at river mouths to track near-field transport over timescales from 1 hour to 1 day.

Figure 16. External appearance and internal assembly of low-cost drifting buoys

Figure 17. General shape and structure of middle-cost sensor-equipped drifting buoys

2.2.5 Modelling of Floating Marine Litter transport

As part of LIFE LEMA, different strategies to guide local authorities on cost-effective FML management were explored using coastal FML transport derived from operational metocean tools. A particle-tracking approach was adopted to model FML transport using surface ocean current fields provided by either observation (High Frequency Radars) or models (regional to coastal ocean model). Two different computing codes were used as part of these applications. The first particle-tracking model (LPTM) implemented in the project was based on the MOHID Water software (Martins et al. 2001; Braunschweig et al. 2004), and more specifically its Lagrangian transport module (Leitão 1996). The second LPTM used in this project was the result of the COSMO Lagrangian model (Garcia-Ladona, 2017). The COSMO Lagrangian model, is a free software available in github repository (https://github.com/quimbp/cosmo). It has been developed at the Institute of Marine Sciences of Barcelona (ICM-CSIC) in the context of the COSMO project (CTM2016-79474-R, MINECO/FEDER, UE).

Main forcing data for the LPTM are surface currents, wind, waves and river flows. Surface current fields used in LIFE LEMA were provided by two sources. The first one was an observational data from a High Frequency Radar (HFR) system, owned by the Directorate of Emergency Attention and Meteorology of the Basque Government Security Department, consisting in two antennas located at Matxitxako and Higuer Capes (Figure 18). Their description is published elsewhere (Solabarrieta et al. 2016; Rubio et al. 2018).

The second source of surface ocean mean current velocity used in this work was provided by a regional ocean model (Figure 19). Hourly modelled surface velocity fields were extracted from the Copernicus Marine Environment Monitoring Service (CMEMS) operational IBI (Iberian Biscay Irish) Ocean Analysis and Forecasting System. A full description of this system may be found in Madec (2008) and Sotillo et al. (2015).

Using this ocean current information, the LPTM computes particle trajectories forward from sources toward destination, or backward from arrival location back toward origin areas. Particle trajectories, densities, and other statistics are thus derived from timeseries of particle positions to obtain information surface ocean transport and FML dispersion (Figure 20).

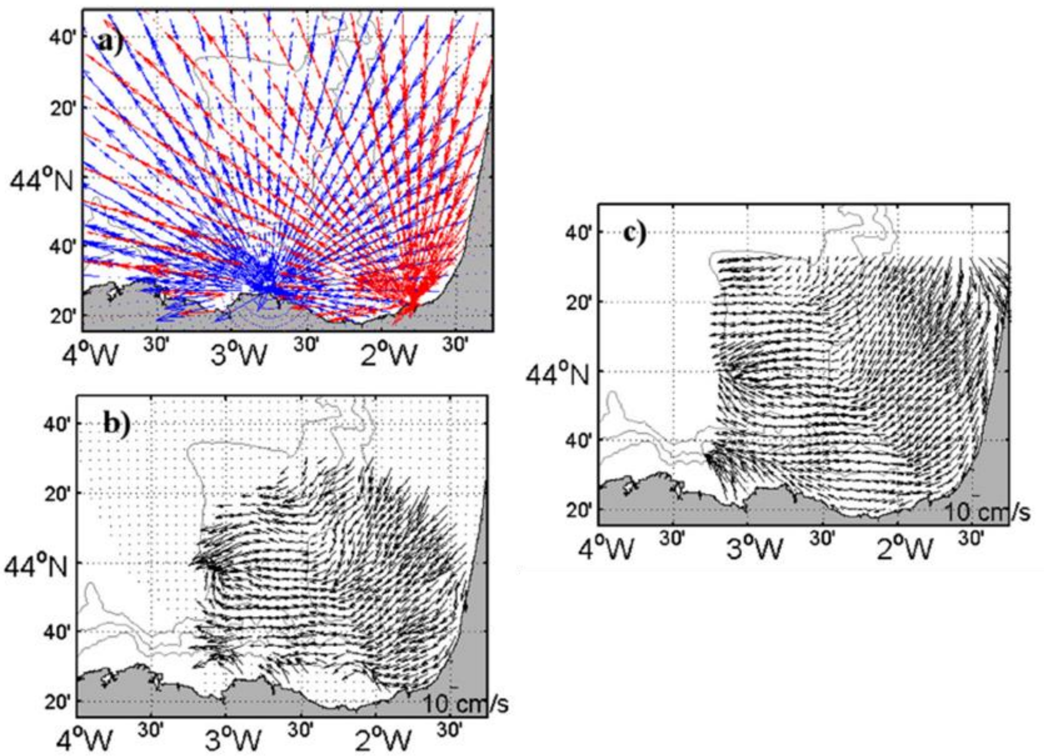

Figure 18: Figure from Rubio et al. (2017). Snapshot of HFR (A) radial and total current fields obtained by using a (B) Least Squares algorithm and (C) the OMA method (Kaplanand Lekien,2007) in the southeast Bay of Biscay.

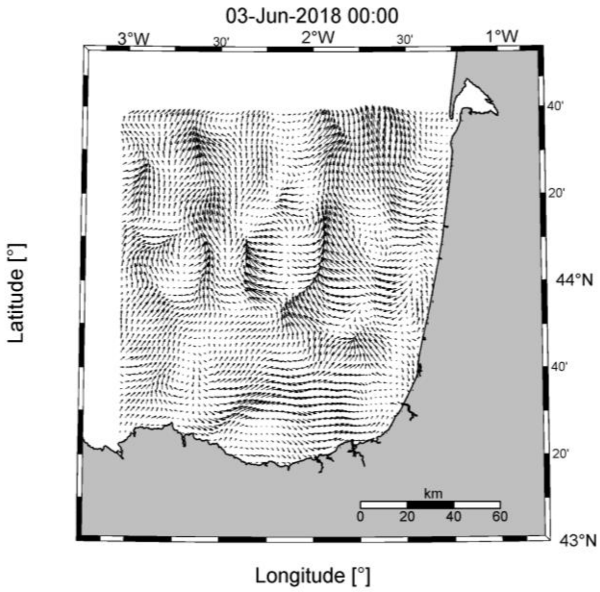

Figure 19 : Example of a surface ocean mean current field provided by the IBI model from CMEMS, extracted on LIFE LEMA study area on June 3, 2018.

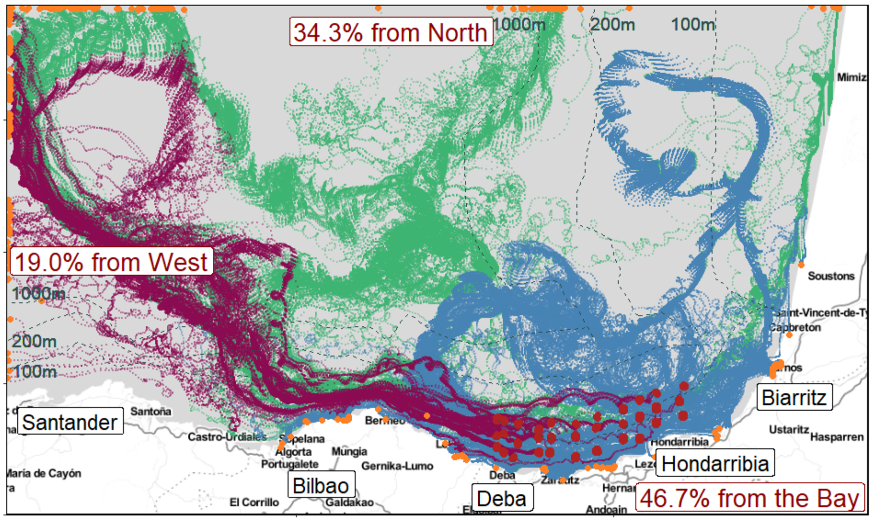

Figure 20 : Example of surface drift trajectories computed from a Lagrangian Particle Tracking Model. Percentages in red font indicate particle origin ratio.

When dealing with marine litter modelling in the coastal area, a major issue relates to properly validate the different assumptions and parametrizations done by the model, consistently with the multiples sources of uncertainty previously mentioned. Consequently, a large effort was conducted as part of LIFE LEMA to implement an FML modelling tool in the study area, and then to assess the accuracy of the different model components against field data. A choice was made here to limit the model complexity at first, and to increase it only progressively in order to be able to properly assess the benefit of additional parameterizations. This is an important aspect of our approach, contrasting with possible more complex but much more hypothetical modelling approaches which sometimes may be disconnected from field reality. Here, a step-by-step and pragmatic progression is preferred to build a favourable basis for future improvements, consistently with the operational and cost-effective objectives of LIFE LEMA.

Following this principle, a variety of field data was used for the validation of the different model components: currents from HF Radars, drifting buoys trajectories, satellite imagery and finally, FML abundance derived from the collect campaigns conducted as part of the project both at sea and on beaches. Then, once assessed the model performances, a set of applications was conducted to support FML management by local authorities in South-Eastern Bay of Biscay. Applications of the modelling tool may be decomposed in two groups:

- A/ offline investigations about FML destination and pathways;
- B/ real time application to support the day-to-day collect operations through the LIFE LEMA Field Tool.

2.3 Decision-support tool: the LEMA tool

LIFE LEMA produced advanced innovative technologies in the fields of data analytics, remote sensing and metocean modelling, as introduced in the previous paragraphs. However, the final tool targeted by the project was intended for end-users who are not experts of these domains, as local authorities, fishermen or beach cleaning services. The tool was also intended to support daily operations, with strong time and efficiency constrains. For that, it integrated the information provided the videometry system, metocean models, alert system, and reports from the LEMA vessels and beach cleaning services within the tool and transformed it to a user-oriented decision-aid indicators through an optimized User Interface.

The decision-support tool developed as part of LIFE LEMA, therefore, aimed at (i) monitoring the collection activities by providing a sustainable database solution, and (ii) guiding operations by predicting floating marine litter dispersion, hotspots and arrivals. The name given to this tool was the "LEMA tool" (Figure 21).

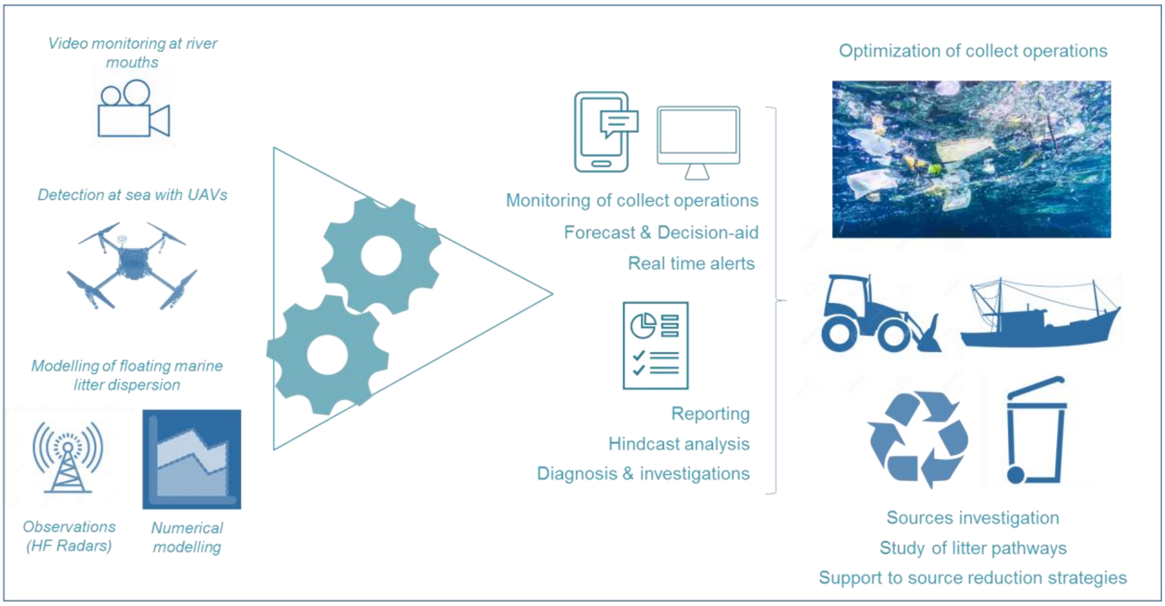

Figure 21 : Schematic view of the components of the LEMA Tool

The so called "LEMA Tool" centralized all the real-time data and information about FML, related collect operations, model predictions and related decision-aid indicators and alerts. The tool made all the different information available through a unique web portal, in a user-oriented way, to all relevant stakeholders including local administrations, fishermen, collect operator, and any other stakeholder involved in FML management. The tool also allowed to store and browse historical data on FML collection efforts.

The core of the system is managed by the (pre-existing) AQUADVANCED® platform of SUEZ, which was complemented by a suite of Python Connectors to collect relevant data like e.g. FML operation reports by fishing vessels and collect teams, or vessel GPS track. The platform ensures data processing, numerical models management, data analytics, and connects to the web User Interface to make all this information available for end-users.

The User Interface was accessible on the web by a computer, tablet or smartphone, with an optimized graphical approach dedicated to mobile devices (*progressive web app*). It allowed to bring a large range of information to end-users, from integrated decision-aid indicators up to detailed data on metocean conditions or any other data. The UI was fed in real time by operational systems, and it can provide alerts in case of specific configurations. Finally, it also offered to enter information on field to allow cleaning teams and fishermen crews to give a daily feedback on their missions (time of operation, amount of FML collected, etc.). This information was sent back to the system to be integrated in the analysis, and allowed to derive indicators to monitor the results and efficiency of collect operations.

3 Results

3.1 FML collection in LIFE LEMA

a) FML collection by LEMA vessels

The amount of FML collected in the duration of the project is listed in Table 1. Wood collection is also included as part of the French vessel FML collection campaign. Such collection was part of the contract, whereas the collection of wood was omitted in the Spanish counterpart.

Table 1 : Collection of FML by the LEMA vessels, in kg

Collection of FML (*wood*)	2017	2018	2019	TOTAL (kg)
Miren Argia	385[1]	1,109	no activity	1,494
Itsas Belhara	4,200 (10,800)	19,140 (6,000)	12,573 (8,720)	35,913 (25,520)
Uhaina	na	818 (2,681)	757 (2,861)	1,575 (5,542)
BaB Subaquatique	1357 (2,149)	777 (2,002)	915 (2,173)	3,049 (6,324)
Esvat 19	-	734	-	734
TOTAL (kg)	5,942 (12,949)	22,578 (10,683)	14,245 (13,754)	42,765 (37,386)

[1] The collection of the wood was not part of the activity. Figures in *itallics* refer to the amount of wood collected

With the aim of defining its potential sources of the litter encountered in the study area, a total of 11 samples were randomly collected from the big bags for their further analysis in lab. A total 4302 litter items were collected, sorted and characterised according to the Master list included in the "Guidance on Monitoring of Marine Litter in European Seas" (Galgani et al., 2013). Figure 21 shows the results of the characterisation, where the percentage of the contribution is shown by different sources (left column) and type of material (right column).

In terms of number of items, Plastic pieces, strings and cords and Other plastic/polystyrene items were the most common sub-categories found (regardless their origin), comprising over 71.43 %. Regarding the origin and the type of material (Figure 22), Sea-based sources contributed in a 35 % and included primarily items from fishing activities (including aquaculture); string and cords summed the third of the litter collected. Land-based sources related to tourism and recreational activities were not very common in the litter collected and only reached values over 3 %. Very few sanitary items were found in the marine litter, amounting less than 0.8 %. And it must be noted that a large number of items were possible to assigned to neither Sea nor Land-based origin because they were unidentifiable fragments, or their origin could be both. These *Non-sourced* items represented over the 62% of items collected. The importance of this source was highlighted by the fact that plastic pieces (2.5 cm> <50 cm) represented the over the 40% of total items encountered. Packaging items (food and drink) consisting of drink bottles, food containers, and what remains of rip-off plastic bags accounted for 6.68 % of Non-sourced origin items. Single-use plastics, entering the ocean from multiple sources and pathways, account for 18.5%.

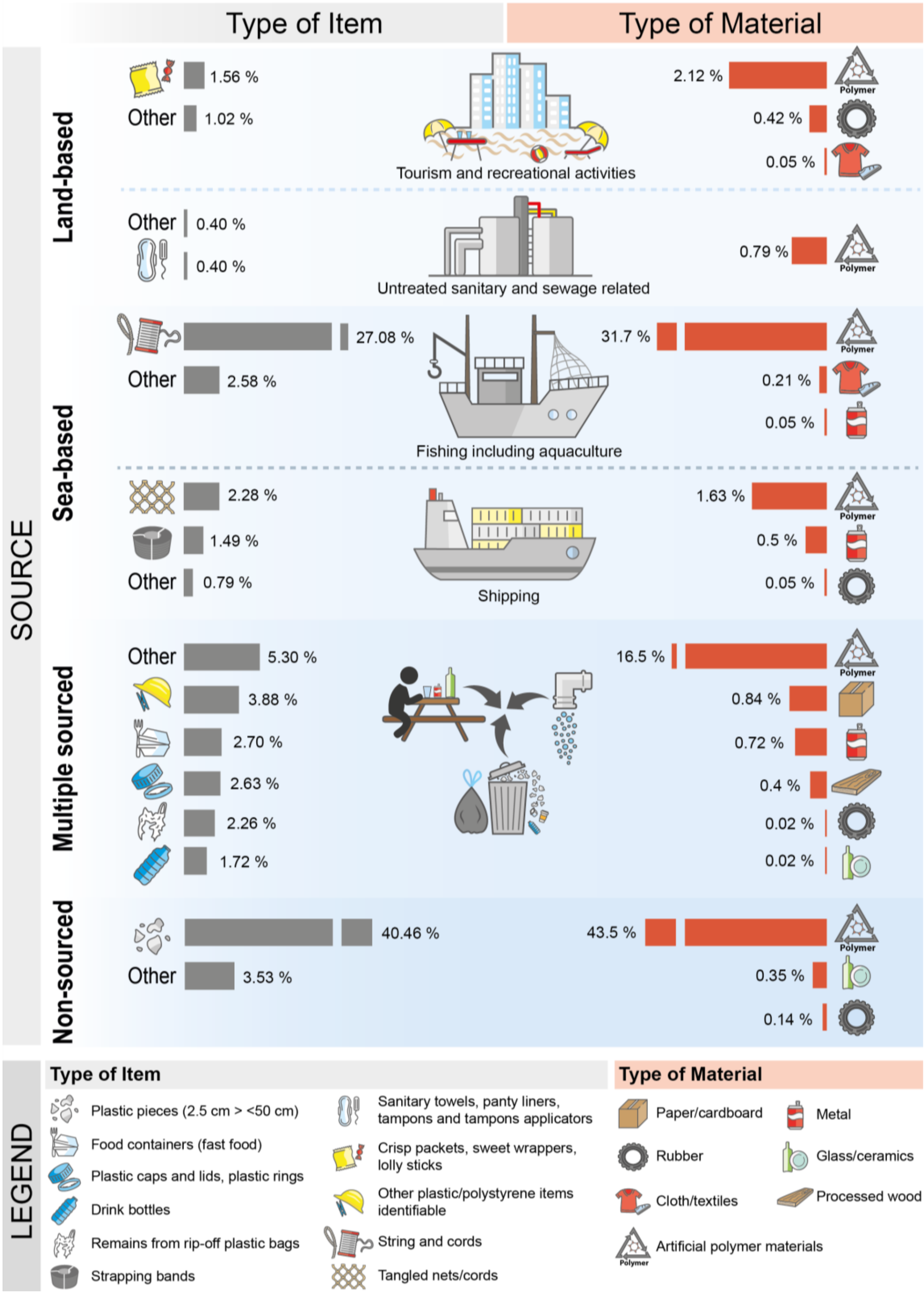

Figure 22 : Percentage of litter items collected per source and related to type of material (Illustration by Agustina Taglialegna) by the LEMA vessels.

b) Microplastic abundance in the SE Bay of Biscay

The results from the microplastic survey revealed an uneven distribution of litter on both coasts. Three times higher concentrations were found in average on the French coast than on the Gipuzkoa coast. To highlight the temporal variability of microplastic abundances and enable the comparison between months, the abundances are represented in a boxplot (Figure 23), where the average values of each campaign are marked with a x, and the median is indicated by a line across the box.

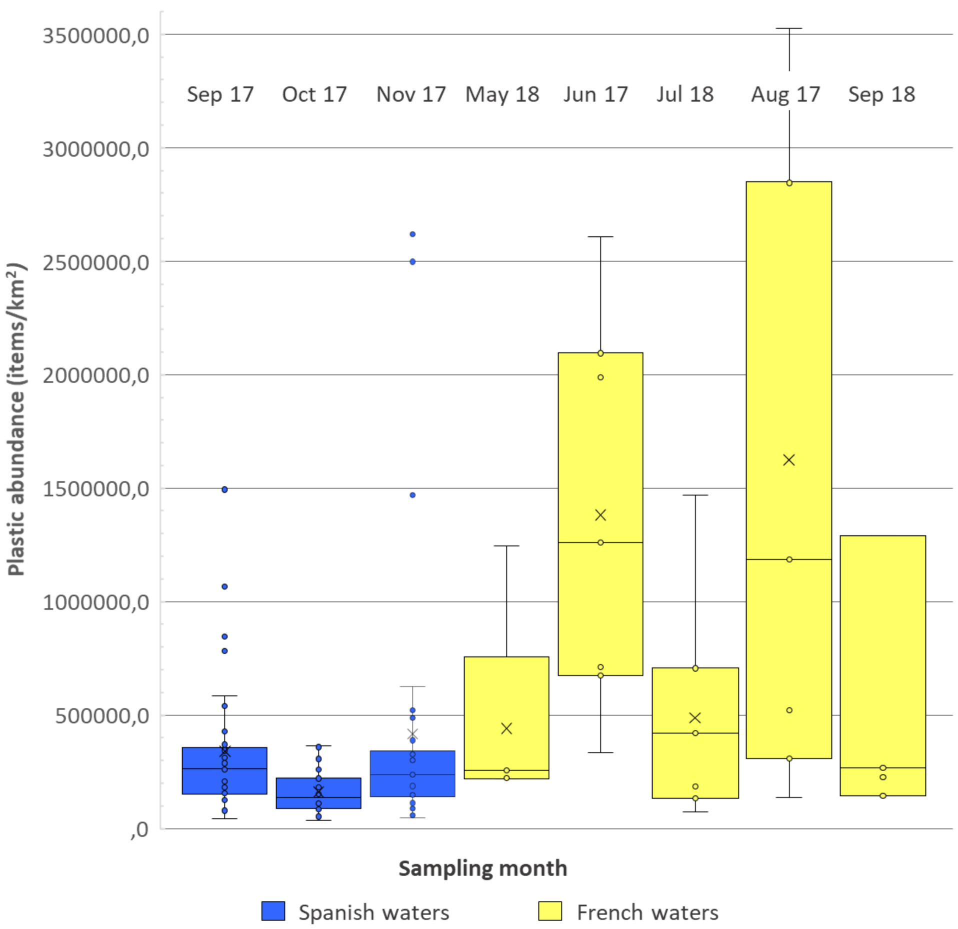

Figure 23 : Estimated microplastic abundances from 2017 and 2018 microplastic LEMA surveys. Results from Spanish (Gipuzkoa in blue) and French (Labourd in yellow) coastal waters.

In 2017, the abundances ranged between 35,632 and 2,618,971 items.km^{-2}. The highest concentrations observed were in September (1,493,563 items.km^{-2}) and November (2,497,051 and 2,618,970 items.km^{-2}), whereas in October the lowest maximum value was observed (364,304 items.km^{-2}). In 2018, microplastic abundances were in average much higher than those encountered in 2017.

Nevertheless, during 2018, the samples were undertaken from June to September and along the French coast. An important spatial and temporal variability was observed during this year ranging from 71,492 to 26,384,897 items.km^{-2}. The highest concentrations were measured close to the coast, near the city of Saint Jean de Luz (France) during the months of June, August and September (2,606,109, 3,526,845 and 26,384,897 items.km^{-2} respectively). In July, lower abundances were observed with values ranging between 71,492 and 1,470,731 items.km^{-2}.

c) Beach litter collection:

Regarding the litter collected in beaches by the cleaning machines yearly and the manual daily collect during the summer season, the amount collected in 2017-2018 was almost 3,000 tonnes of beach litter by mechanical collection and almost 3.7 tonnes by manual collection (Table 2). Furthermore, the related dataset and feedback contributed largely to improve the knowledge about marine litter dynamics, validating monitoring and modelling techniques, and assessing decision-aid tools and management strategies.

Table 2 : Collection of beach litter

	Amount of marine litter collected (kg)	
	Mechanical collection	Manual collection
2017	1,135,150	1,186
2018	1,789,180	2,482

According to the OSPAR campaigns conducted in 3 Spanish coves with volunteers (coves of Murgita in Donostia-San Sebastian, Burumendi in Mutriku, and Inpernupe in Zumaia), the top ten items encountered in these beaches were:

1. Plastic/polystyrene pieces 2.5- 50 cm
2. Drinking containers (bottles, containers and drums)
3. String and Cord
4. Plastic/polystyrene pieces 0 - 2,5 cm
5. Food container
6. Glass items
7. Ceramic/Pottery items
8. Construction material
9. Plastic bag ends
10. Caps/lids

Based on the number of collected items, approx. the 62% of the total amount of items encountered were collected in Winter and Spring (31% each), the 23% in autumn and the 15% in summer.

d) Riverine litter collected by the barrier

During the second half of the month of March and April, due to heavy rains and the high flow rate of the river, the barrier was unable to operate as intended (Figure 24). Heavy, continuous rains caused a lot of materials to be dragged along (trunks, branches, rubbish, etc.) which filled up the barrier and, together with the high flow rate of the river, exerted a very high thrusting force on the barrier that moved it downstream on several occasions (images b and c). In addition, the materials that were dragged along by the river built up on the beach of Ondarbeltz, as shown in image (d). Nonetheless, from May to June 15, the barrier has carried out its functions without any significant problems.

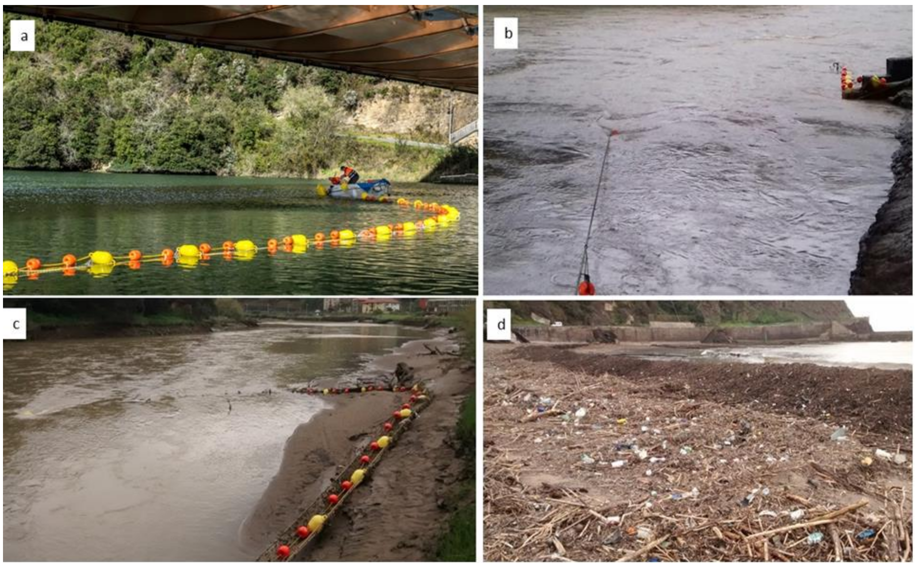

Figure 24 : Illustration to show the (a) barrier installed on the River Deba, (b and c) position of the barrier during heavy rains (c) waste accumulated on the Ondarbeltz beach after heavy rains in March and April.

After the period of heavy rains, from the second half of April onwards the barrier carried out its functions without any significant problems. However, the amount of litter collected by the barrier was low (71 kg during the period it was installed). This may be due to the fact that the litter in urban spaces and on the riverbanks had already been washed away during the period of heavy rains. Some litter samples were taken and characterised in lab and as the results show, most of the litter was plastic in everyday use, such as food packaging.

Based on the experiment carried out at the mouth of the River Deba, we can conclude that the effectiveness of the barrier was strongly influenced by the intensity and torrential nature of the rainfall and the resulting river flow. It should be noted that the River Deba, and the rivers in Gipuzkoa in general, are short, with a steep slope, with many channelled sections and a relatively low flood control capacity under high rainfall, which means that it is not the type of river to which the floating barrier is best suited, at least in times of intense rainfall.

As result and comparing with the other technology's tested in LEMA project, the barrier was shown to be the least effective technology for collecting floating litter.

3.2 Monitoring and modelling technologies

3.2.1 Detection in rivers with videometry techniques

a) Developed technology and information provided

The developed algorithm is based on the definition of an area, made of virtual barriers, to detect and track all the floating objects that pass through this area. The algorithm has an initial barrier, where the floating objects are detected, and a second barrier where a tracker verifies that the same floating objects have reached the second barrier in the downstream direction (Figure 25). Moreover, a calibration area was set, to calculate the sizes of the detected objects, considering the characteristics of the camera and its position. The standard processing cycle of the algorithm is shown in Figure 26.

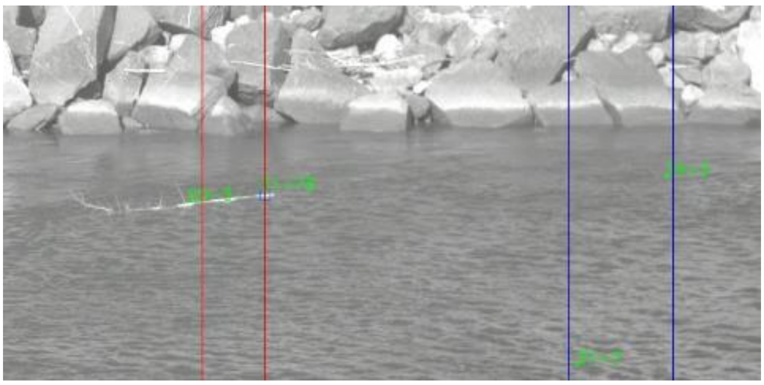

Figure 25 : The initial virtual barrier (in blue) and the second barrier (in red) of the algorithm. Detected FML are indicated in green.

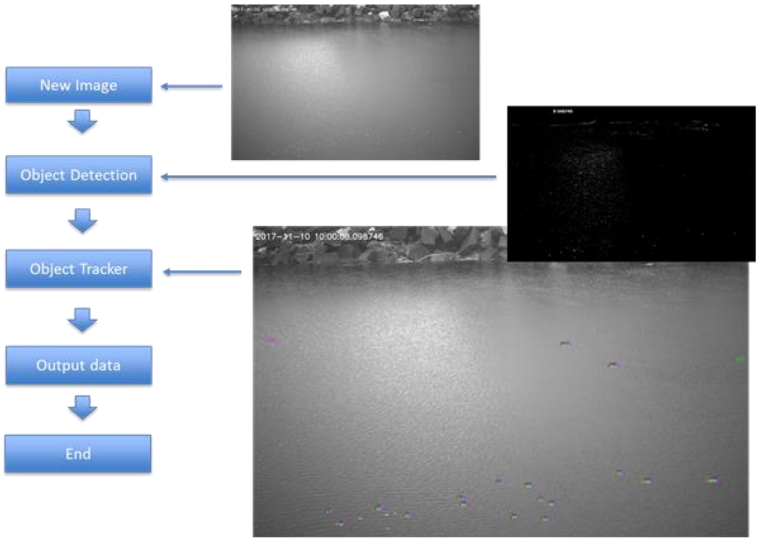

Figure 26 : The processing cycle of the algorithm.

To fulfil the objective of providing a quantitative estimation of the floating object abundance in a river, the algorithm provides specific outputs in a form of a report (an example is shown in Figure 27). This report is generated continuously in periods defined by the user (i.e. one report every 60 minutes). Each report contains the following information:

- Average size of detected blobs in the period
- Average speed of detected blobs in the period
- Maximum and minimum blob size in the period
- Maximum and minimum speed in the period
- A list of detected blobs in the exit area. Each blob has its average size and speed during the detection time.

```
---------------------------------
---------------------------------
New report: 2018-05-11 09:51:04.314485
---------------------------------
ID: 56; Ypos: 315; Size: 7.85398; V: 139.697546063
ID: 14; Ypos: 256; Size: 25.132736; V: 94.2452892798
---------------------------------
Blobs overrun cycles: 0/124
Max Size: 25.132736
Min Size: 7.85398
Average Size: 16.493358
------------END------------------
---------------------------------
---------------------------------
New report: 2018-05-11 09:51:24.441388
---------------------------------
ID: 23; Ypos: 311; Size: 8.6786479; V: 116.219279777
```

Figure 27 : a report generated by the algorithm.

b) Validation of the technology

A specific work was conducted to validate the algorithm and assess its performances. The testing of the algorithm was based on the comparison between the reports provided by the algorithm for selected videos and the visual observation of the same videos by AZTI staff. The validation was based on 14 videos; each video lasting up to 1 hour. They were recorded in consecutive days and they corresponded to different metocean and daylight conditions. The number of blobs identified in the analyzed videos totaled 2,014 by the algorithm, resulting in 1,190 observations in the visual testing process, considering an extrapolation of the 3 partially analyzed videos. The maximum number of testing observations in any video was 250 and the minimum number was 1. Results are illustrated in Table 3.

Table 3 : Overview of results reported and tested. Videos partially analyzed (sample) in orange.

Video n°		01	02	03	04	05	06	07	08	09	10	11	12	13	14
Report	N° of reported blobs	240	29	1	550	105	1	316	141	408	85	63	41	21	13
	Density	H	M	L	H	H	L	H	H	H	M	M	M	M	L
Analyzed N° blobs		240	29	1	250	105	1	100	141	100	85	63	41	21	13
Test	N° of observed items	0	2	1	247	34	1	1	27	4	20	0	2	2	0
	Real density	L	L	L	H	M	L	L	M	L	M	L	L	L	L

Thus, the onshore detection system, based on video imagery and processing, gives promising results and can be considered as operational in its first version. Indeed, it is able to provide real time information about the qualitative abundance of FML being transported toward sea at a river mouth. It is important to point out that there are many cases where the algorithm has worked correctly. By avoiding the three most common types of errors highlighted in the previous section (sparkles, reflections and foam formation), the accuracy of the algorithm will be strongly reinforced. The use of filters is recommended to eliminate the noise derived from different conditions of brightness, wind and rain change. Therefore, unlike indoors, it is necessary to consider that there will be non-static elements in the image.

c) Demonstration of the technology

Monitoring data from both Orio and Adour video stations were finally connected to the LEMA Tool in early 2019, and demonstrated in final configuration during summer 2019 demonstration. Related timeseries of number of litter detected by both stations are given in Figure 28.

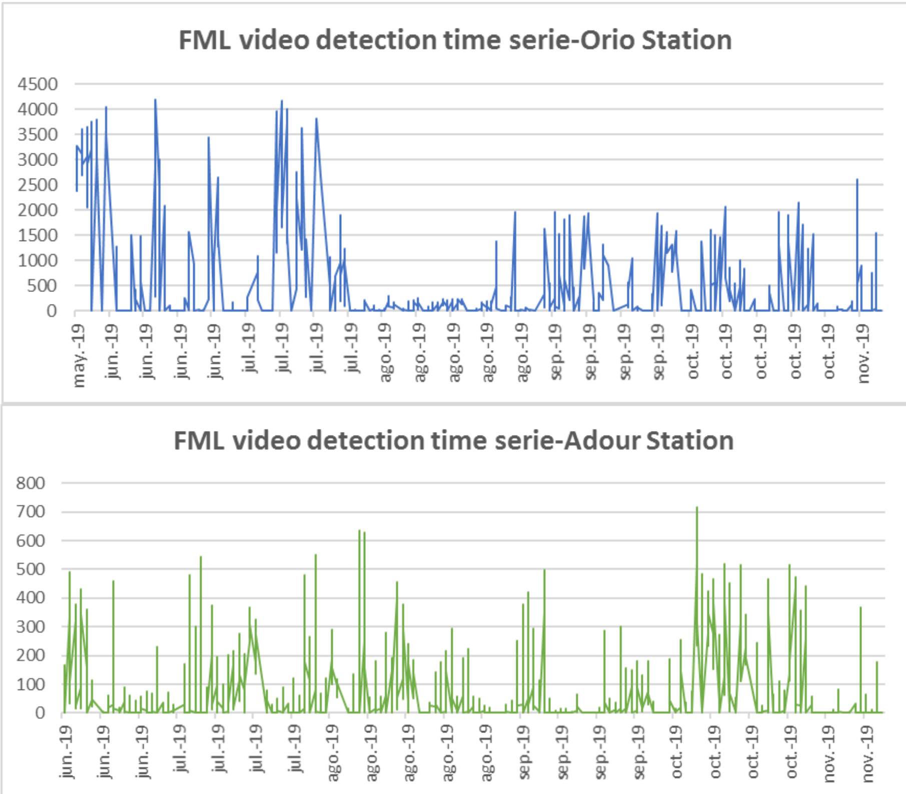

Figure 28 : FML video detection time series in Orio and Adour stations.

3.2.2 Detection at sea from UAV images

a) Developed technology and information provided

During the test missions, the feasibility of the drone deployment in the coastal environment was assessed from 1/ the shore (3 flights performed) and 2/ from a FML collection vessel (aborted flight due to adverse metocean conditions).

The drone was equipped with sensors collecting images of the sea surface. Both an optical RGB sensor and a multispectral sensor were used to collect images and assess their respective suitability for FML detection. The images collected during these test flights were further used to develop an algorithm for FML automatic detection in the aerial images. Two automatic detection approaches were tested, one based on machine learning procedure and the second using marine optics properties to identify FML at sea.

b) Validation of the technology

Realization of the flights in the coastal environment was revealed as quite challenging, with significant restrictions from regulation as well as from meteorological conditions. The drone technology especially could be optimized in the future to better fit the constrained related to the coastal environment (wind, distance, etc.). Although this was not the purpose of the action planned in LIFE LEMA, which was focused on the demonstration of the image processing-based detection capacity, drone technology optimization was identified as a perspective of further improvement.

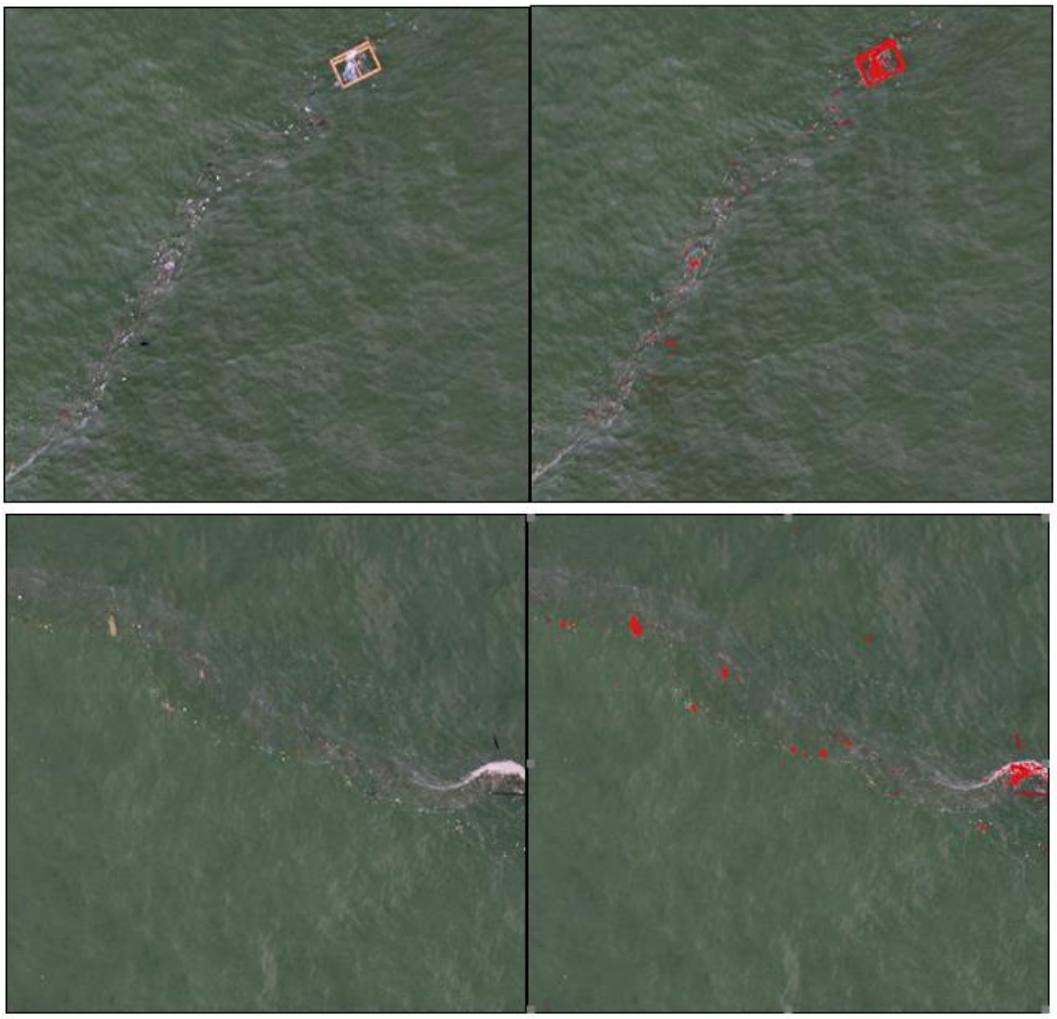

Figure 29 : Illustration of the results of automatic detection of coastal FML accumulation from drone imagery. Left: image collected by the drone with glint and radiometric corrections. Right: results of the detection algorithm, with detected debris highlighted in red.

Regarding all sensor used and the several methods performed to detect FML at sea, the results confirm the feasibility of using UAV imagery to assist the ground collection of floating wastes at sea. Especially, best results were obtained with (1) the RGB optical sensor and (2) the machine learning detection algorithm. The combination of these two components provided encouraging results in the detection of FML accumulation as well as in the identification of large isolated objects, and possibly the estimation of FML densities in the case of accumulation. Results from the image processing are illustrated in the Figure 29 below.

A significant difficulty remains in false detection induced by foam, which is still hardly distinguished from white reflective plastic objects. A larger set of images could contribute to increase the training sample for the algorithm, and possibly help improving this aspect.

3.2.3 Surface transport observations with drifters

a) Developed technology and information provided

Surface drifters presented in paragraph 2.2.4 were deployed in the SE Bay of Biscay during several experiments. Depending on the type of drifters deployed, different level of information was provided: wooden drifters provided data about drifters' onshore arrival, while satellite drifters provided detailed GPS trajectories across SE BoB.

b) Satellite drifters releases at river mouth

Satellite drifters were released at the following river mouths: Deba, Oria, Urumea, Adour, Bidassoa and Nivelle. For the first 4 rivers, buoys' fates were classified into 4 mainly categories according to their type of arrival: (1) coastal water arrival, (2) entrapment, (3) shoreline arrival – other, (4) shoreline arrival – beach. Results obtained is given by Figure 30.

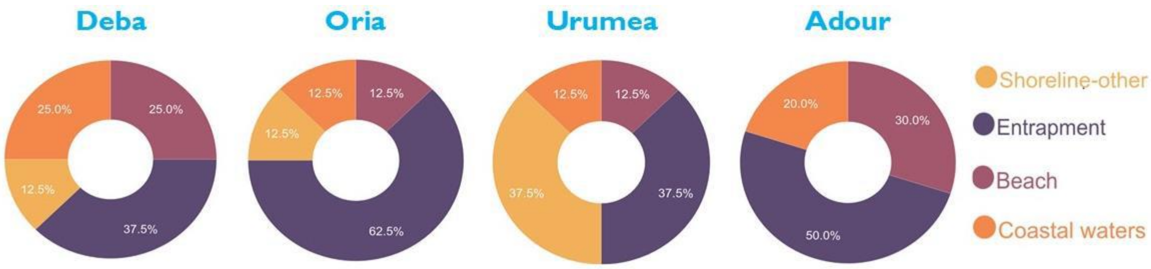

Figure 30 : Classification by type of arrival for each river.

The results point to a high rate of entrapment both in riverbanks and breakwaters since over half of the buoys (47.06%) didn't leave the immediate surroundings of the releasing locations. Beach arrivals accounted for 20.59% of the total arrivals and 17.65% of the buoys reached the southeastern coastal waters of the Bay of Biscay. Only 14.41% of the buoys floated before their arrival to the French and Spanish coastal cliffs. Buoys were more likely to get trapped in Oria river mouth (62.5%) though during the whole experiment at least one buoy got trapped in every river mouth. Almost half of the buoys released during the experiment were recovered (41.46%) and reused in the subsequent campaigns.

Cross-analyzing trajectories with metocean conditions led to the following main conclusions:

- the highest number of entrapments (≥ 60% releasings for every river) and beach arrivals (25% in Oria and Urumea rivers) occurred at low flows ($Q<10$ m^3/s), particularly during summer 2018 and autumn 2018. There is no evidence that high flows were directly related to coastal waters arrivals;

- During high and medium tidal coefficient periods, the likelihood of entrapment was over 50% for all the rivers. The maximum entrapment values with greater than 60 % probability occurred mainly at medium tidal coefficient. Although higher tidal coefficients are directly linked to strongest ebb currents, coastal waters arrivals increased during low tidal coefficient periods, concurring with winter 2019 releasings.

- In most cases, buoy launches were taken up during periods of low intensity winds (85.23%) concurring with prevailing northerly conditions (52.94%). The highest entrapment rate occurred under these conditions (20.59%), probably favored by orientation of the river mouths, especially in Gipuzkoa, where rivers flow in a south-north direction. Only punctual entrapments (8.82%) took place during strong wind periods (>10 km/h). Coastal waters arrivals occurred also at low intensity winds, mainly during northeasterly periods (50%) though rest of wind directions influenced buoys leaving the river mouth.

c) Satellite drifter releases in open ocean

Some examples of the surface drifting buoys released in the open waters of the Bay of Biscay are presented below (Figure 31). The results show that the shape and weight of the buoys is critical for the drift. Observed trajectories were confronted with a transport model to study this effect, together with the contribution of the windage coefficient and angle.

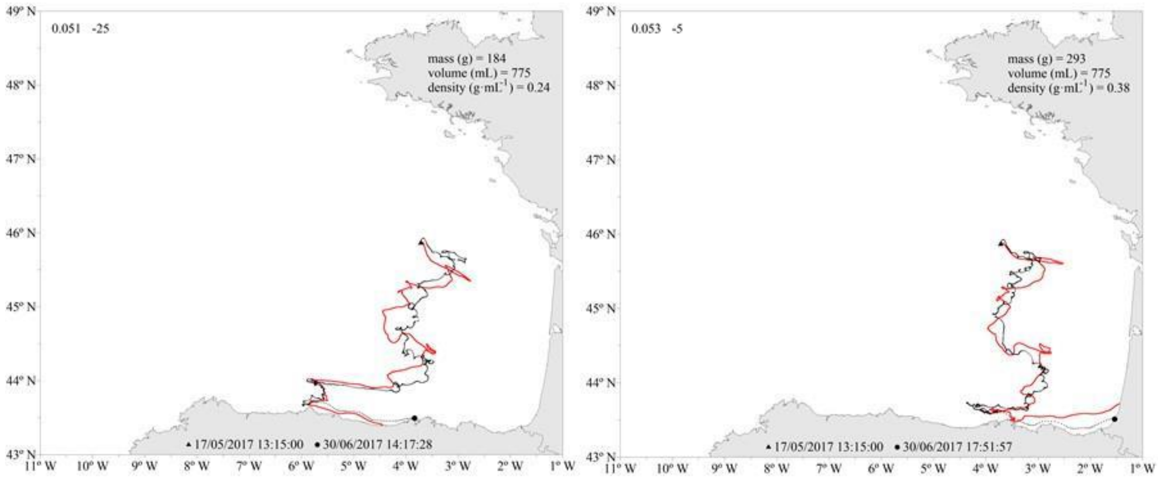

Figure 31 : Trajectories of two surface drifting buoys released at the same time and location, but with different weight, 184 g (top) and 293 g (bottom). In black the real trajectories and in red the simulated ones with the parametrization located at the top left of the image.

The general trend of buoys launched in the Bay of Biscay is to go to the Spanish or French coast, and always to the east rather than to the west. This indicates that the marine litter that present in the area tends to go southwest, being difficult to leave the Bay of Biscay. The best model results were obtained when we used a windage coefficient between 0.04 and 0.06 and a deflection angle between 0° and 25°. A large part of the drifter trajectory is explained by wind contribution, which may be related to the shape and buoyancy of the buoys.

d) Wooden drifters

Between 2017 and 2019, 24 boat launch campaigns were carried out in the open waters of Asturias (ES), Santander (ES), Basque Country (ES) and different points in the Bay of Biscay. At each boat launch point, the day and time, and the latitude and longitude positions were recorded. When the boats arrived at the coast and were found by coastal users, the following information was requested: longitude and latitude coordinates, day and time of the finding, and photo of the boat.

The information from wooden drifters provided very useful additional information as a complement to satellite drifters. Corresponding data were used to optimize and validation the parameterizations of numerical models of FML transport as exposed in the next paragraph. Figure 32 below shows an example of such a model-data comparison for RADIALES-20 campaign carried out in December 2017.

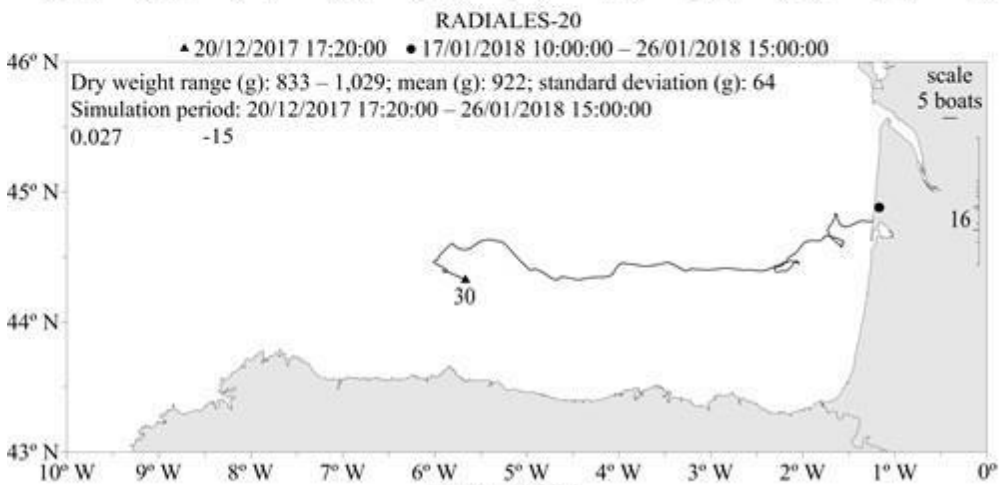

Figure 32 : Characteristics of the wooden boats found (16 of 30) after the RADIALES-20 campaign and the coastal area where the boats were found. In black, we show a simulated trajectory which was obtained using a numerical model simulating FML transport.

Using these two campaigns as an example of the others, it can be presumed that the drift of the boats is largely influenced by the wind. Moreover, the results of the campaigns indicate that the drift of the boats, as in the case of surface drifting buoys, goes generally from west to east (in more than 95% of cases). This confirms the hypothesis that it is very difficult for marine litter to leave the Bay of Biscay once they are inside the gulf.

3.2.4 Modelling of Floating Marine Litter transport

a) Developed technology and information provided

The modelling tools developed as part of LIFE LEMA relies on the so-called "particle tracking" approach to simulate floating marine litter transport in the surface ocean layer. Particle-tracking is a specific numerical modelling approach consisting in simulating the displacement of numerical tracers in space and time. The current particle-tracking application to floating marine litter transport considers that the transport velocity is given by an ambient current field which represents the mean ocean current velocity, plus other possible contributions that can be added to the movement like e.g. turbulent mixing, Stokes drift or direct wind-induced drag. Moreover, parametrizations specific to marine litter are added into the model, like e.g. the contribution of possible litter sources or processes like beaching on very shallow water.

As a primary result, the computation provides the timeseries of positions of numerical tracers across the computational domain, from their point of introduction or source, up to their destination, as illustrated in Figure 33 (left). Then, to extract useful information from the raw model output, different post-processing and statistics are derived from tracers' position. Among other variables, the tracer density is of particular interest as a proxy of floating marine litter abundance. The tracer density is computed by integrating the tracer positions information on a fixed spatial grid (in black on Figure 33 left panel), resulting in density maps as illustrated in Figure 33 (center).

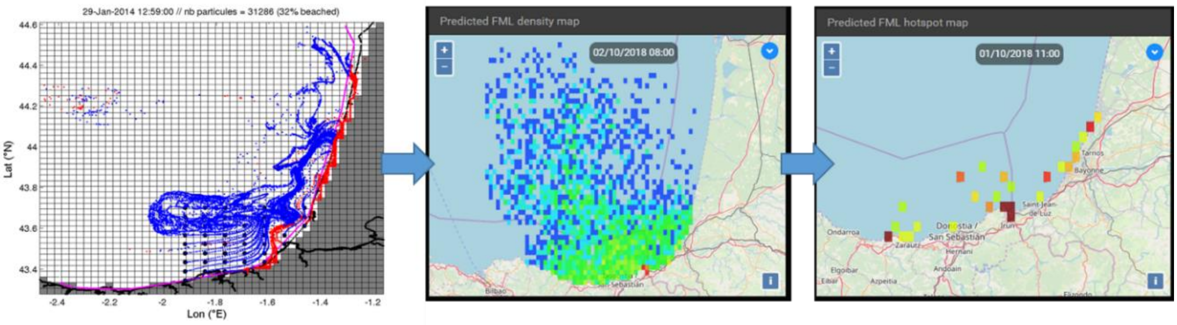

Figure 33 : (left) Raw output from the FML Lagrangian module forced by IBI model currents; (Center) Density maps computed from the Lagrangian particles distribution; (Right) Focus on highest densities or "hotspots".

Then, as part of LIFE LEMA two types of information was derived from density maps. First, relative indicators may be derived like most probable location of floating marine litter hotspots (Figure 33, right), or increasing/decreasing trend from a day to the next one. When using the model for backward transport, from the arrival back to the origin, possible sources of marine litter may be also evaluated. Second, absolute quantification may be sought, i.e. a weight in kg or density in kg/m^2 of floating marine litter, or any related indicators like abundance range. This was done by searching for a relationship between modelled tracer densities and observed marine litter amounts, the later information being provided by the monitoring of collect campaigns described in paragraph 3.1 and detection systems presented in 3.2.1 and 3.2.2.

Finally, a set of integrated decision-aid indicators were computed and provided to end-user from the different model post-processing outputs, allowing to get rapid and easy-to-use indication regarding expecting floating marine litter hotspots, abundance, temporal trend or origin.

b) Validation of the technology

A significant effort was conducted as part of LIFE LEMA of assess the accuracy of the different model components against field data, and the validate the related prediction capacities. This is an important aspect of our approach. This detailed validation step is thought to be essential for a proper use of modelling results as a support to FML management. Indeed, the evaluation of model accuracy is required to confirm that decision making can, actually, rely on model results and to what extent, i.e. how model-derived indications should be used in regard to the unavoidable model uncertainty.

The conducted validation work relies on model comparison with several types of data, with the aim of evaluating properly the accuracy of the different model components. To assess the surface ocean transport representation by the model, results were first confronted to GPS drifter measurements and to ocean color satellite imagery. Second, the particle-tracking model was assessed by comparing model results forced by HFR and by IBI model current. Transport patterns obtained from both forcing were confronted to evaluate their consistency. Part of this work was published in Journal of Operational Oceanography by Declerck et al. (2019). An illustration is given in Figure 34 below, which compares modelled density fields obtained from HFR and IBI model current forcing over a 3-years hindcast, for both annual mean and seasonal averages.

Finally, model results were compared to the main variables targeted by the whole simulation chain: observed FML densities or quantities, as reported during the 2018 and 2019 demonstration campaigns. This last step provides the overall uncertainty of the model and the derived decision-aid indicators. Different types of model-data comparison were performed. Figure 35 provides the comparison of modelled and observed amounts of floating marine litter on Biarritz beaches during the 2019 summer season. Variability is compared at different monthly, weekly and daily timescales. Figure 36 shows the corresponding model-data comparison for the abundance indicator, quantifying the range of marine litter to expected on the beach.

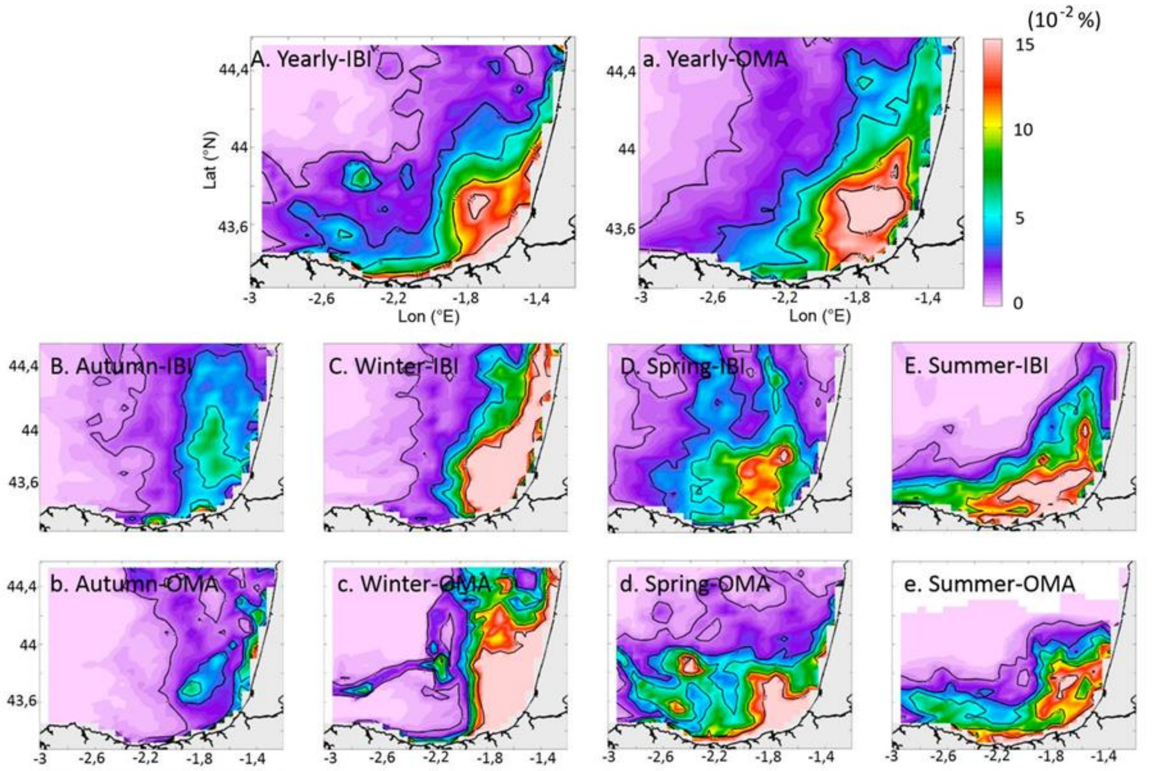

Figure 34 : Normalized density maps computed from COASTAL simulations forced by IBI (left) and OMA (right) currents. Densities are averaged at different timescales: yearly (A, a), autumn (B, b), winter (C, c), spring (D, d) and summer (E, e). Normalized densities are computed following (1). (Figure extracted from Declerck et al. 2019).

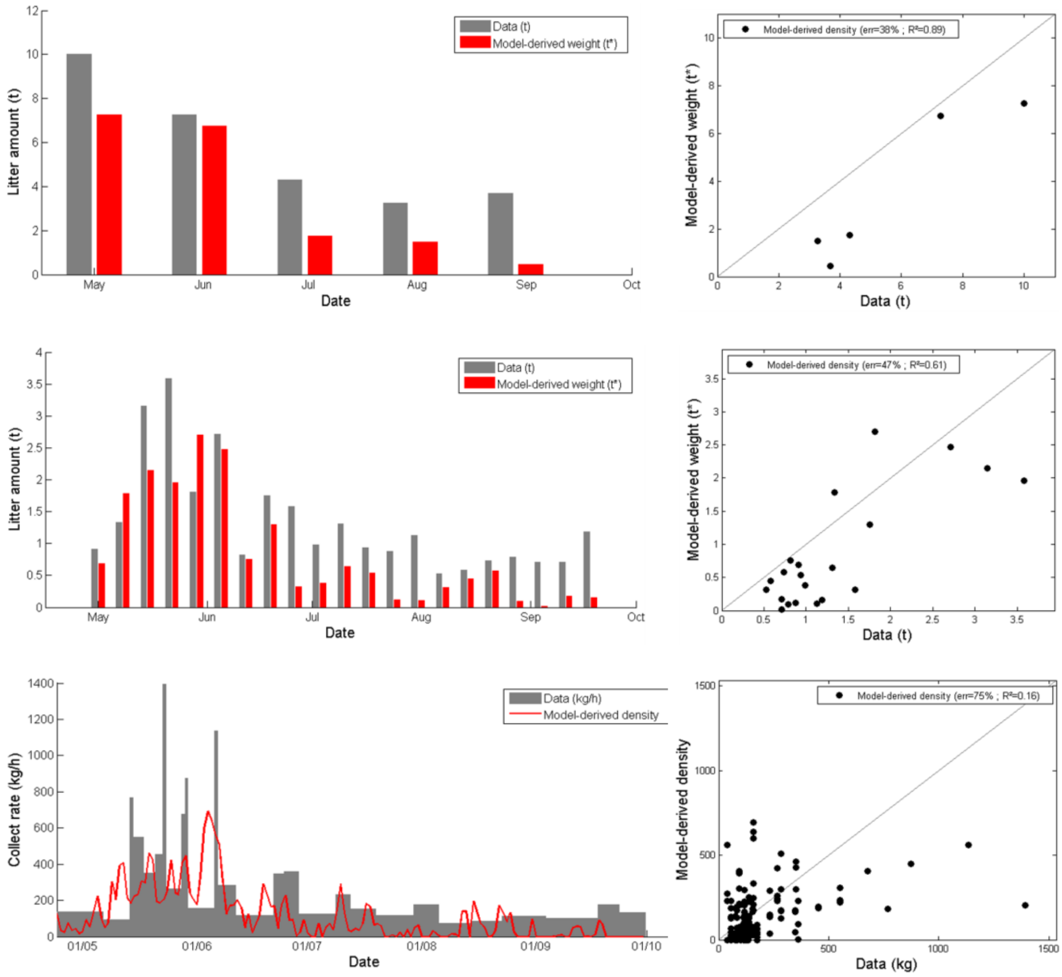

Figure 35 : Model-data comparison on the VALIDATION dataset for Biarritz beach. (Top) Monthly, (center) weekly and (bottom) daily FML amounts. Left column gives model and data timeseries, right column gives correlation graphs including model error (RMSE) and model-data correlation (R^2).

This result (Figure 36) confirms the fair capacity of the model to predict the abundance ranges on Biarritz beach. The abundance index is well predicted 76% of the time, and is predicted with a -+1 uncertainty 97% of the time. Moreover, most important peaks are generally present in the model timeseries, either well predicted or with -+1 error. Although discrepancies remain on this daily basis comparison, leaving room for further improvements, results obtained are considered very encouraging for the future, while already confirming the usefulness of model FML predictions on Biarritz beach.

Same type of model-data comparison was performed for offshore collection data to assess the model capacity to predict floating marine litter accumulation in the coastal area. In that case, errors obtained were higher than for onshore arrivals. Totally, the abundance index is well predicted 63% of the time, and is predicted with a -+1 uncertainty 96% of the time. This may be attributed to the higher floating marine litter variability in the coastal area, and possibly also to the possible occasional decorrelation of collect data with real litter presence in that case. Finally, for the coastal area, an additional comparison could be made with feedback from sea trips, which were provided by fishing vessels' crew during the collect campaigns thanks to the LEMA Tool. Corresponding results are illustrated in Figure 37, which supports again the overall consistency of the model representation.

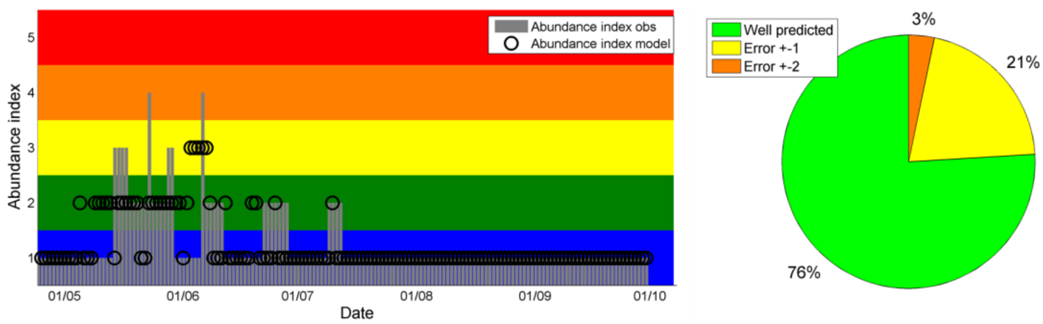

Figure 36 : Left: observed (gray bars) and modelled (black circles) abundance index timeseries. Right: distribution of model-data differences in the abundance index. Results for Biarritz VALIDATION dataset.

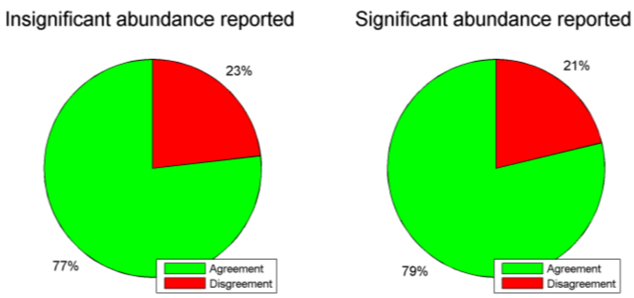

Figure 37 : Comparison of model results with feedback from Itsas Belarra sea trips. Two categories of feedbacks were provided (insignificant and significant presence) for the 5 geographical sectors of the vessel operations. The graphs give the agreement/Disagreement between model-derived indicator and feedback for both categories.

c) Demonstration the technology

After the validation phase, the modelling tools presented above were used as part of different applications to support the management of FML by local authorities. Main applications conducted are the following:

- Investigation of FML transport processes
  - Modelling the sources and destination of macro litter in the SE Bay of Biscay
  - Modelling the sources of microplastics in the SE Bay of Biscay
- Operational application for daily forecast and decision support

Results obtained from both type of applications are illustrated below.

Investigation of FML transport processes in the SE Bay of Biscay

Results from application a) are first illustrated by Figure 38 and Figure 39 below. In Figure 38, mean seasonal patterns of surface ocean transport were extracted from density maps computed over a 5-years hindcast simulation of the model. Figure 39 illustrates the simulated pathways and destinations for the microplastics observed during Life LEMA. From the density maps we also observed different patterns for the different years and months, in general more particle density is observed close to the coast in 2018, which agrees with the observations which show higher microplastic densities in 2018. Other factors like the different coverage of 2017 and 2018 surveys and different local sources could contribute to the observed differences, thus further research will be needed to better characterize the observed variability.

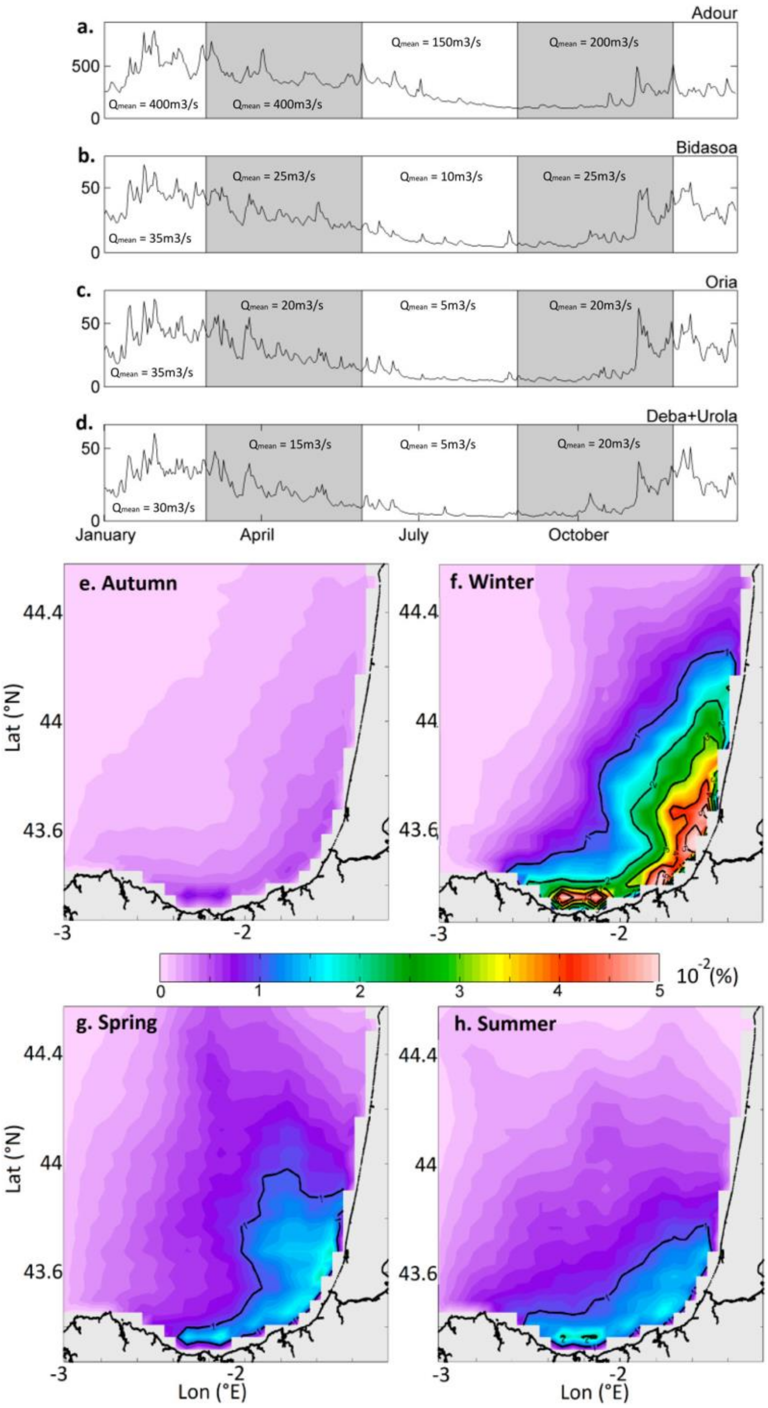

Figure 38 : Seasonal variability of river inflows and resulting transport pattern computed from RIVERS run results. Multiyear mean of river inflow in m3 s−1 for the Adour (a), the Bidasoa (b), the Oria (c) and the sum of Rivers Deba and Urola (d). For each season and river, the averaged flow (Qmean) is also indicated. Seasonal normalized density maps computed from RIVERS simulation for autumn (e), winter (f), spring (g), and summer (h) (seasonal averages from 2013 to 2017). (Figure extracted from Declerck et al. 2019).

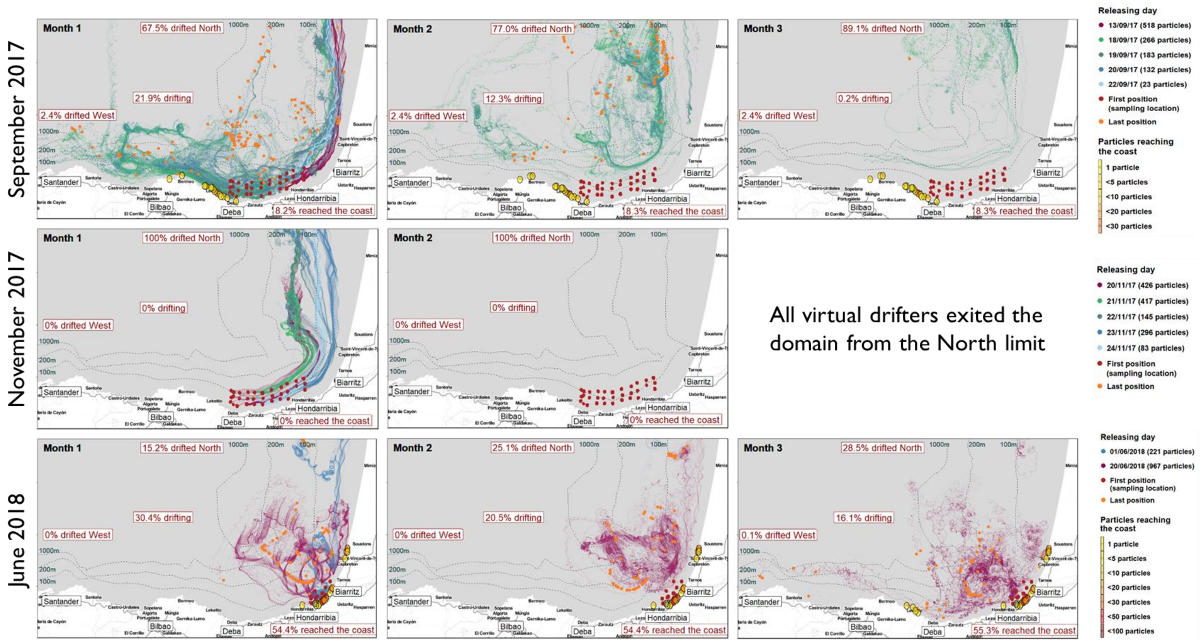

Figure 39 : Three months' forward drift simulations of microplastic particles encountered in September 2017, November 2017 and June 2018 stations. Release point of the drifters (first position) is shown in red, the last position in orange. The trajectories followed during the simulation are shown in distinct colours for each day sampled.

Main conclusions obtained regarding FML pathways and destination are summarized below:

- Results obtained emphasize significant retention in the southern part of the domain during summer when the continental outflow is low, mainly due to wind-induced circulation. Conversely, an intense northward transport along the French coast is obtained during autumn and winter seasons driven by the intensified IPC. This northward flux facilitates coastal flushing in autumn, whereas in winter it does not compensate the increased river inputs, resulting in the highest material densities along the French coast.

- The large variability of wind regimes results in a broad range of pathways for FML at shorter time scales, with significant spatial and temporal variability. This is especially remarkable during the summer season, which is critical in terms of FML coastal retention, while wind patterns are highly variable.

- Whatever the season or the wind regime, results show that particles tend to stay between the coast and the 200m-isobath, suggesting the presence of a transport barrier at the offshore shelf limit, which could be related to IPC slope current flowing in the area. The existence of such a transport barrier was demonstrated by e.g. Ourmières et al. (2018) and Mansui (2015) for the Northern Current along the north-western Mediterranean coast.

- Finally, we also observed different patterns for the different years and months. In 2018 especially, remarkably higher particle densities are observed close to the coast, which agrees with the observations.

Complementary to the above-mentioned forward simulations representing FML destination, simulations were also performed to investigate FML origins, using the so-called "backtracking" computation mode. When using the backtracking mode, particle-tracking computation is carried out backward in time. Thus, this procedure allows to reconstruct particle trajectories from the arrival point back in time to previous positions adopted by tracers, up to possible emission points or areas. This methodology was applied to both macro and micro litter observations collected during the project. Results obtained are illustrated in Figure 40 for microplastics: backward transport is computed from concentrations measured in the coastal area, and related origins' contributions are quantified.

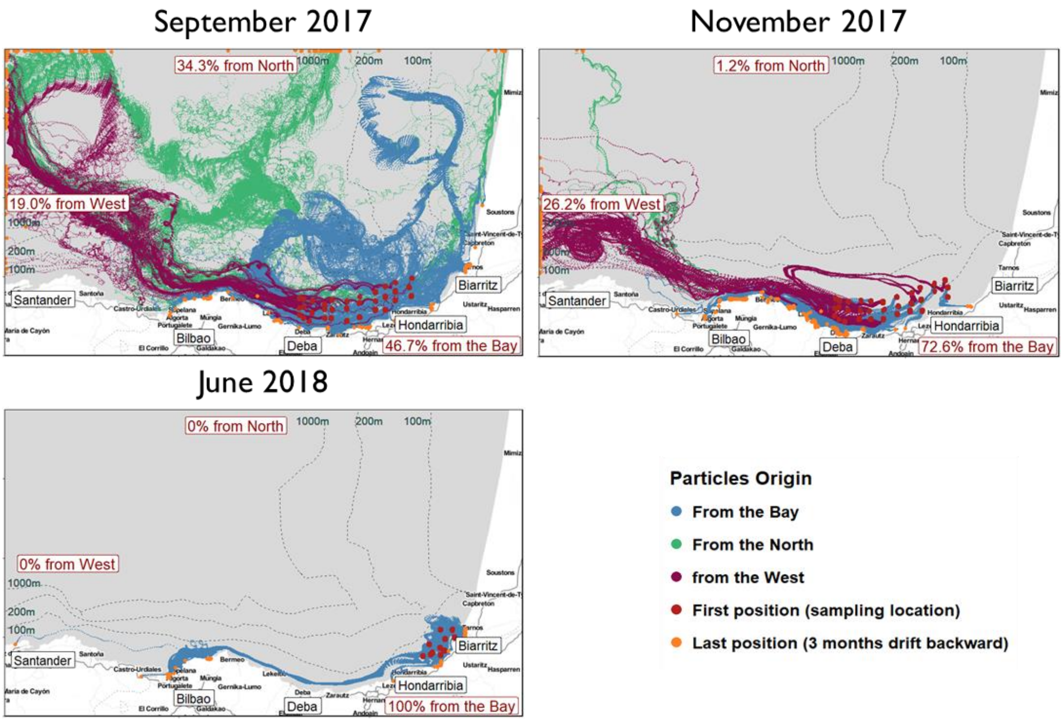

Figure 40 : Origin of the microplastic particles encountered in September 2017, November 2017 and June 2018 samples by three months backtrack simulations. Depending the origin of the microplastic particles, a specific colour was attributed to their trajectories.

Main conclusions obtained about FML origins are summarized below:

- For macro litter: the analysis revealed very different pathways for macro FML depending to the studied event (local, distant and remote sources where identified), which relates to the significant space-time variability of surface ocean currents in the studied region. Three main sources were identified in the southeastern Bay of Biscay. An expected major source is the Adour estuary. A secondary alternative FML pathway was suggested from the Bidassoa/Nivelle estuaries, while another pattern corresponds to a remote western origin from which FML are transported along the Spanish coastline up to the collect areas. Ultimately and with generally more limited contribution, in some scenarios part of the FML may come for the open ocean.
- For microlitter: as for macro, the origin and destination of the microplastics found in the coastal waters of the SE Bay of Biscay strongly depend on the metocean and environmental variables. Although no clear pattern could be obtained neither temporally nor spatially in the studied months, most of the particles were backtracked to the coast of the Basque Country, highlighting the high residence times in the area for the analyzed periods. In addition to local sources the arrival of microplastics to the area from the western and norther boundaries is also observed in spring/autumn and summer months respectively, in coherence with the variability of the surface current regime in the area (e.g. Solabarrieta et al. 2014).

Operational application for daily forecast and decision support

For application b), the model was used in real time, to produce daily forecasts from which decision-aid indicators were computed for the support of collection campaigns. For this application, model setup corresponds to the best parameterization obtained from the calibration/validation work presented earlier. The model was transferred into the LEMA Tool to be operated in real time. Surface current forcing from CMEMS-IBI model were collected every day to feed the model, as well as river flows for the most significant local rivers considered in our study. Then, the model was run once a day over a prediction horizon covering the next 2 days.

The necessary post-processing to compute decision-aid indicators, like e.g. the abundance index, was implemented. Finally, a decision-aid indicators were updated daily and gave information about the configuration to be expected for the next 48h. Examples of model-derived indicators provided by the LEMA Tool are given in the next section.

3.3 Decision-support tools: demonstration and validation

The LEMA Tool centralizes all the real-time data and information about FML, related collect operations, model predictions and related decision-aid indicators and alerts. The tool makes all the different information available through a unique web portal, in a user-oriented way and available on both computers and mobile (*progressive web app*), to all relevant stakeholders including local administrations, fishermen, collect operator, and any other stakeholder involved in FML management. Information are available through a main dashboard, complemented by detailed subpages focusing on different system components. Main types of information available in the tool are summarized in the figure below (Figure 41).

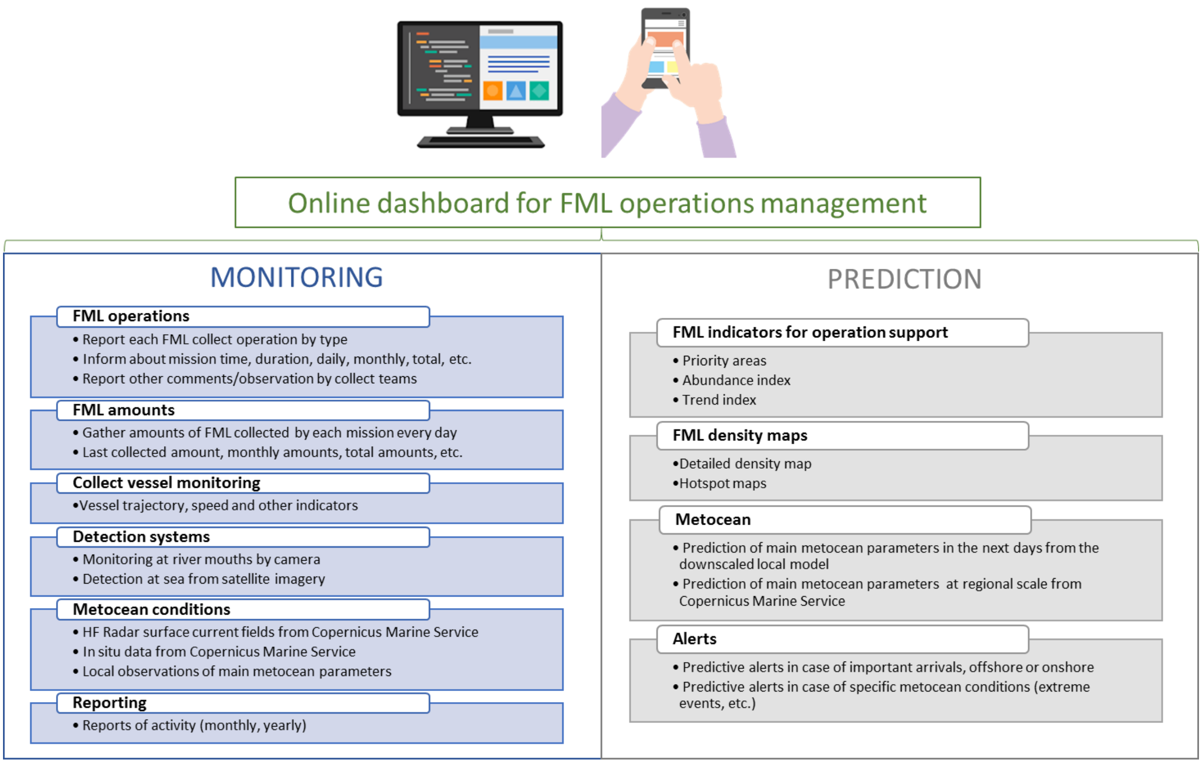

Figure 41 : Components and information managed by the LEMA Tool.

Next figures provide illustrations of different types of information available in the tool. Figure 42 illustrates collect operations monitoring data for fishing vessels: for each sea trip, the vessel trajectory and speed are available, as well as the amounts of collected litter, which is reported by the vessel crew through a dedicated online form.

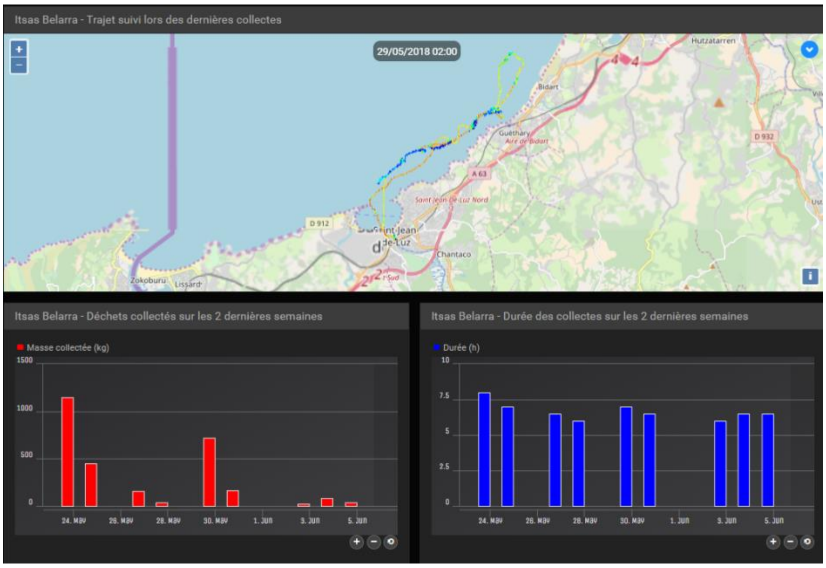

Figure 42 : Example of a dashboard from the LEMA Tool (top: Itsas Belhara trajectory and velocity; bottom: weights of FML collected and collect duration during the last two weeks

Figure 43 and Figure 44 illustrate decision-aid indicators provided by predicting models. Abundance indicators are given to inform about the expected range of marine litter arrivals to be expected in the next days. At sea, areas where most of floating marine litter accumulation is expected are emphasized to support the vessel crews in the orientation of their sea trip, with the aim of maximizing the collected quantities relative to the collect effort in terms of time, field consumption and CO_2 footprint. The tool is also able to produce alerts in case specific conditions are predicted, like e.g. massive onshore arrivals or coastal accumulation of marine litter. Finally, a more detailed level of information may also be found in the tool, like e.g. detailed density maps or hotspots distribution predicted by the model, as illustrated in Figure 45.

Inside offshore the priority zone | Inside the different zones | Onshore

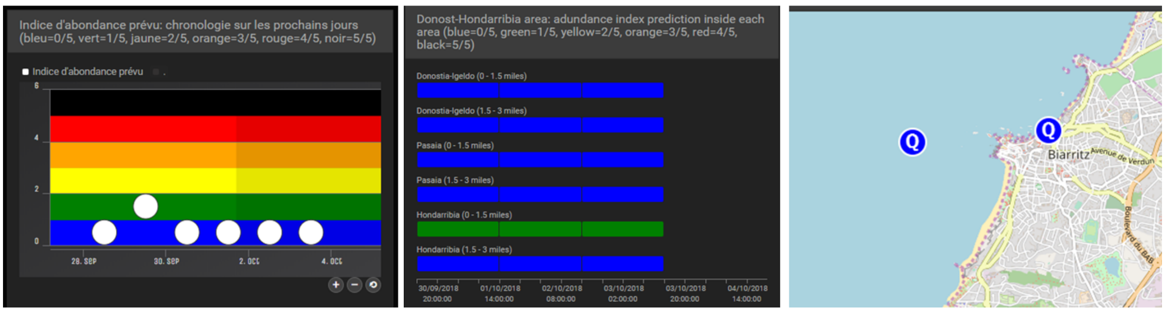

Figure 43: Left: time variation of the Abundance Index inside the priority zone. Centre: time variation of the index in each of the operation geographical areas. Right: onshore Abundance Index on Biarritz beach (the colour of the pushpin gives the predicted abundance level).

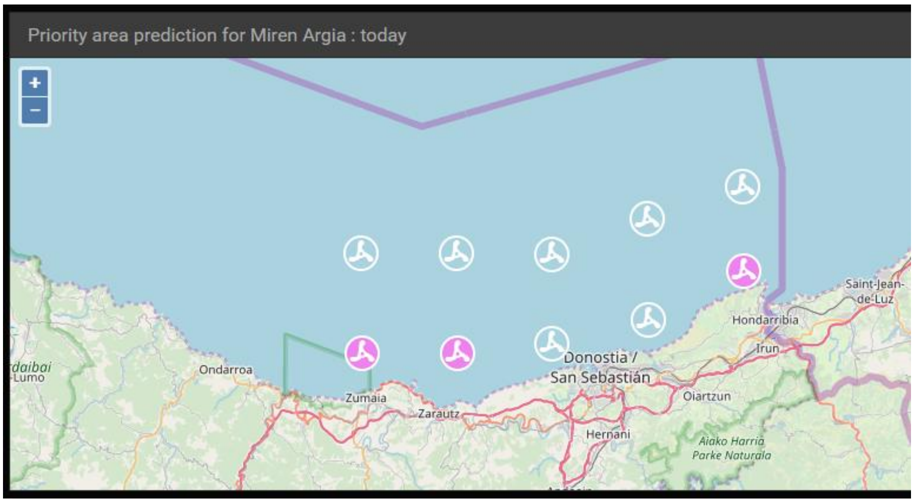

Figure 44: Example of Priority Area indicator provided to Miren Argia crew. Each operation geographical area is symbolized by a white circle. The areas to be targeted are coloured in pink.

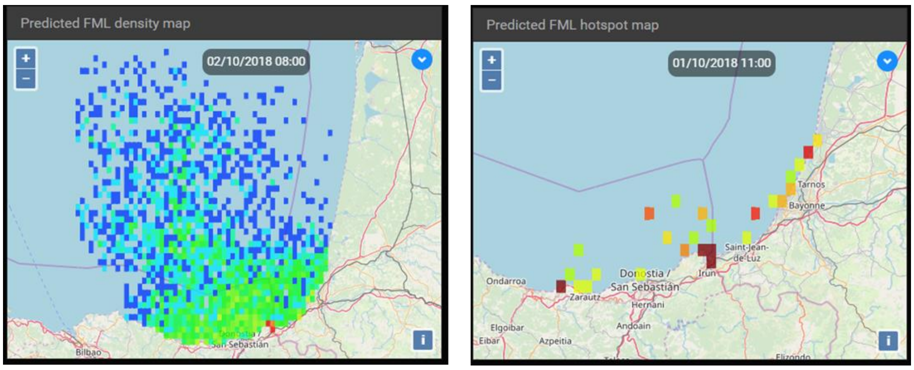

Figure 45: Examples of abundance probability map (left) and hotspot map (right) provided by the LEMA Tool.

The operational application of the LEMA Tool and the use of the related decision-aid indicators were demonstrated during both collection campaigns conducted in 2018 and 2019. During these demonstrations, local authorities, fishing vessel crews and beach cleaning teams involved in LIFE LEMA committed to the use and assessment of the tool. Regular feedbacks were provided to the development teams, which allowed to adjust the tool functionalities at best to the need of the teams on field, as well as to the requirements of the collect operations managers in public administrations. Finally, this involvement and interactions with end-users allowed to validate the usefulness of the LEMA Tool and of the related technologies to support strategies to reduced floating marine litter (see Deliverable DB7.2). This also allowed to integrate this new tool in future strategies, as expressed in the floating marine litter management plan established by LIFE LEMA partners for a concerted, collaborative and optimized strategy (see Deliverable DB7.3).

3.4 Management strategy

During the LIFE LEMA project, a management plan was defined for any local authorities who is willing to commence an implementation strategy to tackle FML. The plan assessed a number of technical-economic aspects that should be considered in order to achieve an effective implementation.

Firstly, the local strategy or plan should contemplate a long-term commitment, a systemic vision of the problem, co-leadership and cooperation among bodies with competences concerning marine litter. Any strategy defined and carried out without the participation of at least the main bodies with competences concerning marine litter should result as a temporary project with poor results and small efficiency. In addition to the institutional cooperation, the strategy ought to contemplate a vision in which the collection of FML is considered to be complementary to prevention and correction at origin, and not an independent corrective measure. Prevention and correction at origin are more efficient and effective in the long-term than removing FML from the sea, a procedure which is more costly and poses greater difficulties.

With respect to the technical and administrative aspects that should be considered prior to implementation of the collection of FML at sea, some aspect should be underlined, such as: authorizations, working methodology and logistic aspects for waste storage and management.

Firstly, the activities planned to undertake must be planned with enough notice because the requested authorizations for marine litter collection can involve a number of different authorities and the permission can be concatenated. At least for Spain the required authorizations include those relating to the activity itself, and others concerning the need to adapt the vessel in accordance with its new activity.

On the other hand, drawing up a deep working protocol will be one of the keys to meet the targets set. The protocol, subject to the peculiarities of the location, ought to start by defining the items of waste to be collected, the working area and the schedule of operations and the period for work to be carried out. The experience acquired in the SE of the Bay of Biscay demonstrates that the litter collection varies depending on the period of the year because of the seasonal metocean conditions (for LEMA project during May-September largest quantities of FML were collected).

However, in order to boost the efficiency of these operations, the involvement of other users of the sea in the campaigns, either through passive fishing for litter, or reports of litter sightings in real time to the vessel detailed to collect it, is a complementary feature with many advantages, such as a greater effectiveness of collection operations and greater awareness of users of the sea. Likewise, resources such as the LEMA Tool which allow operations to be directed towards priority areas has been shown as a collection operations enhancer.

However, tasks to remove FML from the marine environment do not end when the litter is located and taken on board, since a system is required to process it inland. Once the litter is collected it must be labelled and weighted (a rigorous protocol would allow a further investigation on litter sources and marine movement). For litter management, on one hand, should be taken into account that a space for the unloading and temporary storage of the litter in the port should be necessary and, on the other hand, should be defined the management channels for different materials within the territory, preferably considering the possibility of adding to circular economy.

In addition to the technical and administrative aspects, other socio-economic aspects of the project must also be considered prior to the implementation of FML collection. Although there are a number of economic instruments to tackle FML, the principle of "whoever pollutes, pays", in practice it is extremely difficult to materialize because of the undefined sources and origins of materials, among other reasons. Therefore, it makes sense to promote the extended product responsibility throughout the life cycle of a product. Meanwhile, public authorities must exercise the responsibility of guaranteeing a healthy environment. Among the various conclusions drawn from the study such as, for example, identification of the most cost-efficient technologies tested during the LIFE LEMA project, and major uncertainties in the estimation of the benefits of the removal of FML by the authorities, benefits of 2-8 EUR / kg of waste removed were determined for the fishing industry, aquaculture, sea transport and tourism, disregarding the actual benefits of environmental improvements.

The proposed management plan for local authorities and the socio-economic impact of the project are is deeply described at Deliverables DB7.3 and DC2.1, respectively.

As a summary, Table 3 includes some recommendations in order to assist potential authorities applying a management strategy for FML.

Table 3 Obstacles and Recommendations for FML management strategy

Obstacle	Recommendation
Authorisations from administrations	Authorisation for collecting marine litter should be standardised. Each member state should define whether it is possible or not to incentivize fishing vessels and other sea-users for the collection of marine litter. If this was to be the case, a set procedure should be established to facilitate the activity (e.g. authorisations, agents involved….) in a standardize manner.
Legislation	There is a need for a stronger legal framework that includes penalties (polluter pays) or promotes funding and cooperation. The new Port Reception Facilities Directive, the Annex V of MARPOL 73/78 and the European Maritime and Fisheries Fund have already incorporated the Abandoned, Lost and otherwise Discharged Fishing Gears within the policy framework. A similar procedure should be defined for Marine Litter. More work is needed in the Producers Extended Responsibility Directive.
Funding	Funding is required to be able to advance in the technological development to fight against marine litter. Local authorities have limited funding capacity to test new approached. Private funding is also available but often are very competitive and difficult to obtain. The funding from the LIFE PROGRAMME has resulted pivotal to advances in the understanding and fight against marine litter in the SE Bay of Biscay. Thanks to the funding, marine litter has entered into the local political agenda, local school syllabus, and the challenge associated to marine litter has been spread in the general society (inexistent before Life LEMA started). Other funding schemes such as the European Maritime and Fisheries Fund, Horizon 2020, Interreg schemes can provide the opportunity to start working in a new topic such as marine litter and can become the game changer for a region.
Governance	Cross-boundary regions should promote multi-level cooperation against marine litter. Also, a clear distribution of competences and a dedicated legal framework should be established when dealing with marine litter in a cooperative manner.
Technologies	Advanced technologies are essential to support preventive and mitigative actions. Preventive measures have not been dealt in LIFE LEMA. Therefore, the recommendations have focused on the mitigative approach. Technologies are need to: - detect, monitor, forecast and collect marine litter in different environmental compartments: rivers, estuaries, coastal waters, water column, sea bottom, and open sea.

<table>
<tr><td></td><td>Based on LIFE LEMA demonstration:
- The videometry system developed in LIFE LEMA has proved to be promising for detecting and remote monitoring riverine litter. We believe that it is a valid alternative to the riverine litter monitoring by visual observations methods requested by the EU as part of the MSFD.
- Collection of litter by vessels. Active and passive fishing for litter are compatible. Harmonised monitoring and controls of Fishing for Litter (how much is recovered, what type of waste, reporting of the collections etc) and collaborative works between transboundary countries should be promoted.
- Tools that can centralise the information on the detection, monitoring and the collection of marine litter such as the LEMA tool would provide benefits to authorities and agents managing it.
- Technologies to optimise the collection should keep me developing.
- Development of models to forecast the origin and pathways of marine litter should continue, as well as the studies on coastal small-scale convergence areas, patches and/or litter windrows.</td></tr>
<tr><td>Recycling channels</td><td>Establishing a recycling channel for marine plastics and old discarded nets may incentivize the collection of litter at sea by either passive or active fishing for litter initiatives. To make this work:
- Infrastructure and funding would be needed to
o store the collected marine litter
o classify marine litter by type
o clean and prepare the litter for recycling
- Ports would need to be equipped with marine litter disposal and storage points.
- A marine litter management plan should be needed to support all the logistics.
- End-users or the recycled materials should be identified.
- Same conditions should be guaranteed for vessels engaged in active and passive fishing for litter regarding the port fees (e.g. no charging them extra for bringing marine litter to port).</td></tr>
</table>

4 Conclusions

Regarding the environmental benefits, should be underline that the vessels involved at the project have collected 80 tonnes of FML (including wood) during the 2017-2019 campaign.

The innovation and demonstration value of the projects is also worthy of consideration. The main innovation of the project is related to the FML detection, monitoring and forecasting of hotspots in the surface coastal ocean. This LEMA tool supports the increase in collected FML amounts at sea and on beaches, while reducing the carbon footprint of collection activities. The LEMA tool also promotes an improved monitoring of FML abundance in the study area, allowing for an objective evaluation of the local pollution level of the marine environment by FML.

Removing FML from the sea, besides environmental benefits, implies socioeconomic benefits to maritime sectors. The assessment has been focused on, the costs of inaction (cost of having FML in the sea-surface), which is opposite to the benefit derived from the FML removal. According to this study, in the area with higher density of FML the benefit of FML removal exceeds the cost (for cleaning vessels). On the contrary, with low density of FML, the costs exceed the benefits.

The social benefits are also remarkable. One the one hand, the project has created 6 non-skilled jobs linked to marine litter collection by fishing vessels crew that otherwise could not be working during summer season. However, the Spanish authorizations does not consider as an option a fishing vessel from being remunerated and collecting sea waste, which make unviable that waste collection could be an activity entailing diversification of the fishing industry. On the other hand, LEMA project has been an instrument to aware the citizens and the local administration about the local problem of marine litter in the coast of the Bay of Biscay and prove preventive and corrective actions that can be carry on by local administration.

Regarding to project's replicability, on one hand, the FML remote video monitoring system at rivers mouth has been replicated on the Mediterranean sea, Marseille. Likewise, replication of the tool is already advanced on Marseille site.

5 References

Braunschweig et al. 2004 Braunschweig F, Leitao PC, Fernandes L, Pina P, Neves RJJ. 2004. The object-oriented design of the integrated water modelling system MOHID. Dev Water Sci. 55:1079–1090. Elsevier.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M.L., Duarte, C.M., 2014. Plastic debris in the open ocean. Proceedings of the National Academy of Sciences 111, 10239-10244.

Declerck, A., Delpey M., Rubio A., Ferrer L., Basurko O. C., Mader J. & Louzao M. (2019): Transport of floating marine litter in the coastal area of the south-eastern Bay of Biscay: A Lagrangian approach using modelling and observations, Journal of Operational Oceanography, DOI: 10.1080/1755876X.2019.1611708

Galgani, F., Hanke, G., Werner, S., Oosterbaan, L., Nilsson, P., Fleet, D., Kinsey, S., Thompson, R.C., Van Franeker, J., Vlachogianni, T., 2013. Guidance on monitoring of marine litter in European Seas. Publications Office of the European Union.

García-Ladona E. (2017) Currents in the Western Mediterranean Basin. In: Guillén J., Acosta J., Chiocci F., Palanques A. (eds) Atlas of Bedforms in the Western Mediterranean. Springer, Cham.

Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D. W., and Law, K. L. (2012), The effect of wind mixing on the vertical distribution of buoyant plastic debris, Geophys. Res. Lett., 39, L07601, doi:10.1029/2012GL051116.

Laxague, N.J.M., Özgökmen, T.M., Haus, B.K., Novelli, G., Shcherbina, A., Sutherland, P., Guigand, C.M., Lund, B., Mehta, S., Alday, M., and Molemaker, J. (2018). Observations of Near-Surface Current Shear Help Describe Oceanic Oil and Plastic Transport. Geophysical Research Letters 45, 245-249.

Madec G. 2008. NEMO ocean engine: Note du Pôle de modélisation de l'Institut Pierre-Simon Laplace No 27.

Martins F, Leitao P, Silva A, Neves R. 2001. 3D modelling in the Sado estuary using a new generic vertical discretization approach. Oceanol Acta. 24:51–62Leitão PMCFL. 1996. Modelo de dispersão lagrangeano tridimensional [Tridimensional model of Lagrangian dispersion].

Mansui, J., Molcard, A., Ourmi`eres, Y., 2015. Modelling the transport and ac-cumulation of floating marine debris in the Mediterranean basin. MarinePollution Bulletin 91(1), 249–257

Meyerjürgens, J., Badewien, T.H., Zielinski, O., Braun, A., and Butter, M. (2019). "Track of GPS-Drifter North_Sea_Drifter7 in the German Bight, Southern North Sea". PANGAEA).

Novelli, G., Guigand, C.M., Cousin, C., Ryan, E.H., Laxague, N.J.M., Dai, H., Haus, B.K., and Özgökmen, T.M. (2017). A Biodegradable Surface Drifter for Ocean Sampling on a Massive Scale. Journal of Atmospheric and Oceanic Technology 34, 2509-2532.

Ourmiéres, Y., Mansui, J., Molcard, A., Galgani, F., Poitou, I., 2018. Theboundary current role on the transport and stranding of floating marine litter:the French Riviera case. Continental Shelf Research 155(1), 11–2

Rubio A, Caballero A, Orfila A, Hernández-Carrasco I, Ferrer L, González M, Solabarrieta L, Mader J. 2018. Eddy-induced cross-shelf export of high Chl-a coastal waters in the SE Bay of Biscay. Remote Sens Environ. 205:290–304.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2018. Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain). Marine Pollution Bulletin 133, 636-64

Solabarrieta L, Frolov S, Cook M, Paduan J, Rubio A, González M, Mader J, Charria G. 2016. Skill assessment of HF radarderived products for lagrangian simulations in the Bay of Biscay. J. Atmos. Oceanic Technol. doi:10.1175/JTECH-D- 16-0045.1.

Solabarrieta, L., Rubio, A., Castanedo, S., Medina, R., Fontán, A., González, M., Fernández, V., Charria, G., Hernández, C., 2014. Surface water circulation patterns in the southeastern Bay of Biscay: New evidences from HF radar data. Cont. Shelf. Res., 74: 60-76.

Sotillo MG, Cailleau S, Lorente P, Levier B, Aznar R, Reffray G, Amo-Baladron A, Chanut J, Benkiran M, Alvarez-Fanjul E. 2015. The MyOcean IBI ocean forecast and reanalysis systems: operational products and roadmap to the future Copernicus service. J Oper Oceanogr. 8(1):63–79.

UNEP(DEPI)/MED, D.I., 2016. Implementing the Marine Litter Regional Plan in the Mediterranean (Fishing for Litter Guidelines, Assessment Report, Baselines Values, and Reduction Targets).