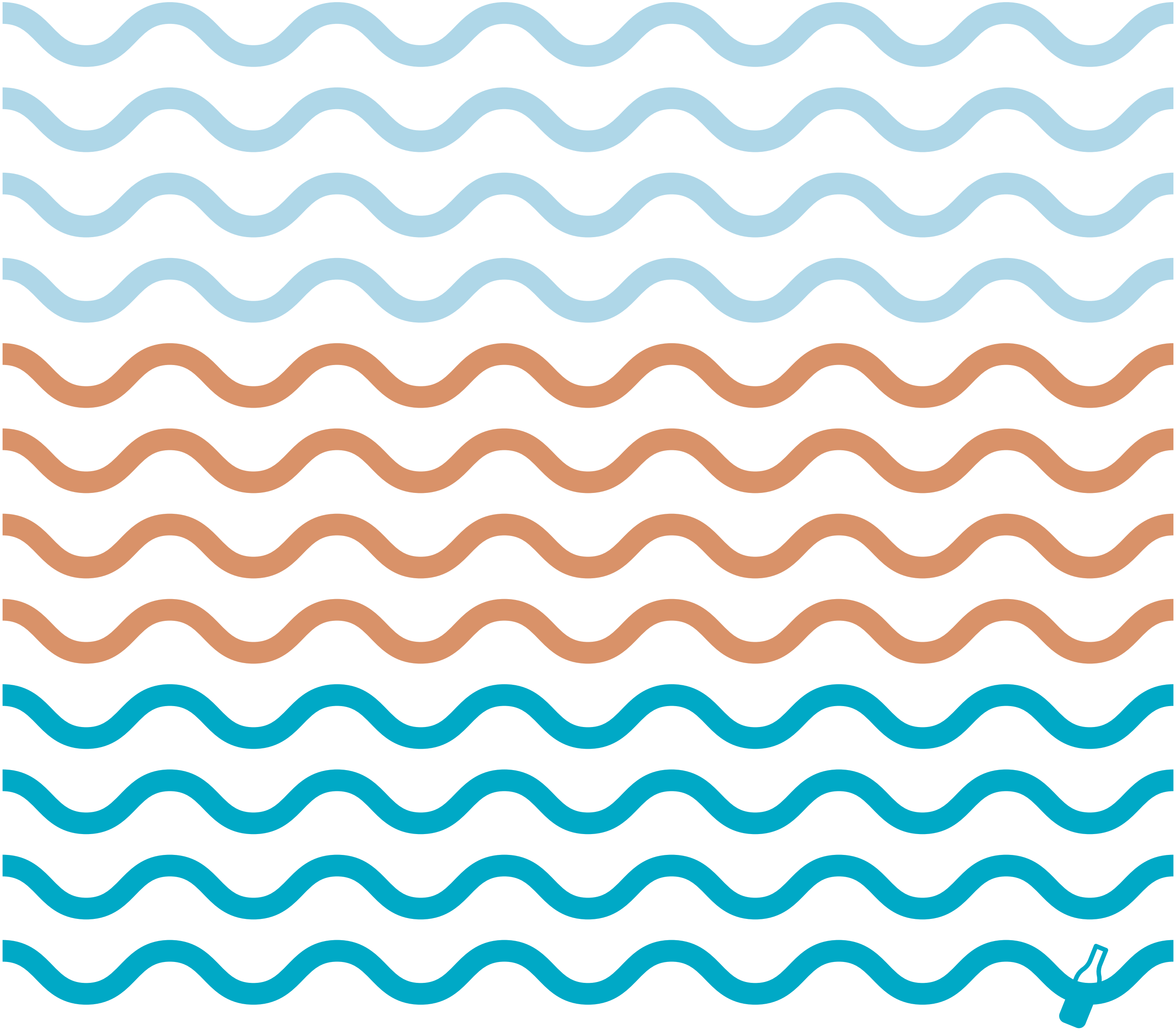
ABUNDANCE, COMPOSITION, DISTRIBUTION AND FATE OF FLOATING MARINE LITTER IN THE SOUTH-EAST BAY OF BISCAY

IRENE RUIZ MUÑOZ

June, 2022

Directors

Dr. **Oihane C.Basurko**
Dr. **Anna Rubio Compañy**



eman ta zabal zazu

Universidad del País Vasco
Euskal Herriko Unibertsitatea

Please, cite this document as:

Ruiz, I., 2022. *Abundance, composition, distribution, and fate of floating marine litter in the south-east Bay of Biscay*. PhD Thesis. Department of Plant Biology and Ecology, University of the Basque Country, 151 pp.

eman ta zabal zazu

Universidad del País Vasco
Euskal Herriko Unibertsitatea

MEMBER OF
BASQUE RESEARCH
& TECHNOLOGY ALLIANCE

ABUNDANCE, COMPOSITION, DISTRIBUTION AND FATE OF FLOATING MARINE LITTER IN THE SOUTH-EAST BAY OF BISCAY

Presented by

IRENE RUIZ MUÑOZ

A thesis submitted to the University of the Basque Country for the degree of

Doctor of Philosophy

Directors

Dr. **Oihane C.Basurko**
Dr. **Anna Rubio Compañy**

Department

Plant Biology and Ecology

Doctoral programme

Marine Environment and Resources

University of the Basque Country

Donostia - San Sebastian, June 2022

CON-
TENT

O

ACKNOWLE-DGEMENTS

There is always something to be thankful for.

Gracias **neskak**. Sois luz. Nunca dejeis de brillar como lo haceís porque iluminais el camino a los que están cerca. Seguid creciendo y creyendo en vosotras. Os mereceis conseguir lo que os propongais.

Gracias **Manuel.** Sin darte cuenta me has recordado en muchos momentos que los camineros también tenemos cabida en AZTI. Sigue haciendo honor a la profesión.

Gracias **Julien**, al equipo de **Tecnologías Marinas** en particular, y al conjunto de compañeros de **AZTI** que me habeis echado una mano cuando lo he necesitado.

Gracias a mis **padres** y mi **hermana**. Sois vosotros los que me habeis empujado a llegar hasta aquí y me habeís enseñado que el esfuerzo tiene su recompensa.

Gracias **Jon**. Bihotz-bihotzez eskerrik asko. Este trabajo es también tuyo. Sin tí no lo habría conseguido. Gu beti pozik, beti alai!

1

LIST OF ACRONYMS, FIGURES AND TABLES

ACRONYMS

BoB	Bay of Biscay
SE BoB	South-East Bay of Biscay
EMODnet	European Marine Observation and Data Network
FML	Floating marine litter
GES	Good Environmental Status
GPML	Global Partnership On Marine Litter
ICPR	International Commission for the Protection of the Rhine
IMAP	Integrated Monitoring and Assessment Programme of the Mediterranean Sea Marine Protected Area
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
OSPAR	Oslo/Paris convention for the Protection of the Marine Environment of the North-East Atlantic
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
SDG	Sustainable Development Goals
UN	United Nations
UV	Ultraviolet

FIGURES

TABLES

2

SUMMARY

This PhD thesis presents a first overview of floating marine litter pollution in the south-east Bay of Biscay through a combination of harmonized observations, sampling methods, and numerical modelling techniques. Abundance and composition of floating marine litter (FML) were assessed combining net tows and visual observations in coastal and open waters of the Bay of Biscay. Floating riverine litter was also collected to explore the floating fraction of marine litter transported via rivers to the south-east Bay of Biscay. Simulations performed at regional (Bay of Biscay) and sub-regional scale (south-east Bay of Biscay) provided insights into the seasonal distribution patterns and fate of fishing-related and riverine litter items according to their observed buoyancy. The model was previously calibrated with data obtained from drifters released in the south-east Bay of Biscay and forced with hourly estimated and measured winds and currents. Data collection in the coastal waters of the south-east Bay of Biscay highlights the occurrence of submesoscale convergence zones for FML ("litter windrows") during Spring and Summer. Fishing, shipping, and aquaculture sectors were the main source of macrolitter (size>2.5 cm) for litter windrows. Abundances derived from sampling the south-east Bay of Biscay revealed that the area is a hotspot for microplastics (size<5 mm). Most modelled particles released both in coastal and open waters did not abandon the Bay of Biscay, reinforcing that the basin acts as accumulation region for FML. Results also demonstrated the impact of buoyancy and wind effect on FML behaviour, mainly in summer, when highly buoyant items strongly affected French Marine Protected Areas and Gipuzkoa and Pyrénées-Atlantiques regions. This thesis represents a milestone for supporting future science and policy actions in the south-east Bay of Biscay oriented to prevent and mitigate FML at local, sub-regional and regional scale.

3

INTRODUCTION

FLOATING MARINE LITTER AS A GLOBAL CONCERN

Floating marine litter (FML) constitutes the fraction of litter less dense than seawater that drifts at the surface layers of the sea due to the effect of wind, waves, and ocean currents after being deliberately discarded or unintentionally lost along beaches, rivers or marine environments. Plastic items made from low density polymers such as polyethylene (PE) and polypropylene (PP) comprises the majority of FML (Galgani et al., 2015). FML is commonly found floating on the nearshore waters shaped as wrappers and plastic bags, and in the open ocean as fishing-related items and plastic caps (Morales-Caselles et al., 2021) (Fig 3.1). FML items can travel for extended periods (weeks to several years) until they acquire some ballast and sink, or they degrade through mechanical abrasion and exposure to UV radiation, and get fragmented (Min et al., 2020). Due to its buoyant nature, FML is globally distributed across all oceans and shores, and can reach remote and uninhabited areas far from the releasing location such as the Arctic Seas (Pogojeva et al., 2021) or the Indian ocean archipelagos (Lavers et al., 2019).

FML transport provides an additional mechanism for the introduction of non-indigenous species, thereby threatening marine biodiversity and the food web, and it represents a navigation hazard (Al-Khayat et al., 2021; GESAMP, 2021).

One of the early records of FML dates back to 1970s when (Carpenter et al., 1972) provided the first evidence of plastic pellet presence in the coastal waters of southern New England. Nowadays, the occurrence of floating micro (size<5 mm), meso (size 0.5–2.5 cm), and macro-litter (size>2.5 cm) has become a well-researched “hot topic” by scientists, particularly in heavily polluted marine basins such as the Mediterranean Sea (Lambert et al., 2020) and in so-called garbage patches at the subtropical gyres (Cózar et al., 2014). So far, the highest concentrations of FML have been recorded in the North Pacific subtropical gyre, where current estimates suggest that at least 80,000 tonnes of plastic items float inside North Pacific Garbage Patch (NPGP) within a 1.6 million-square-kilometre extension area (Lebreton et al., 2018).

Efforts have been also made in recent years to addres s the submesoscale patches of FML (structures with size ranges from a few meters to 10 km in length) with remarkable litter densities and traditionally overlooked in scientific literature (Cózar et al., 2021) (Fig 3.2).

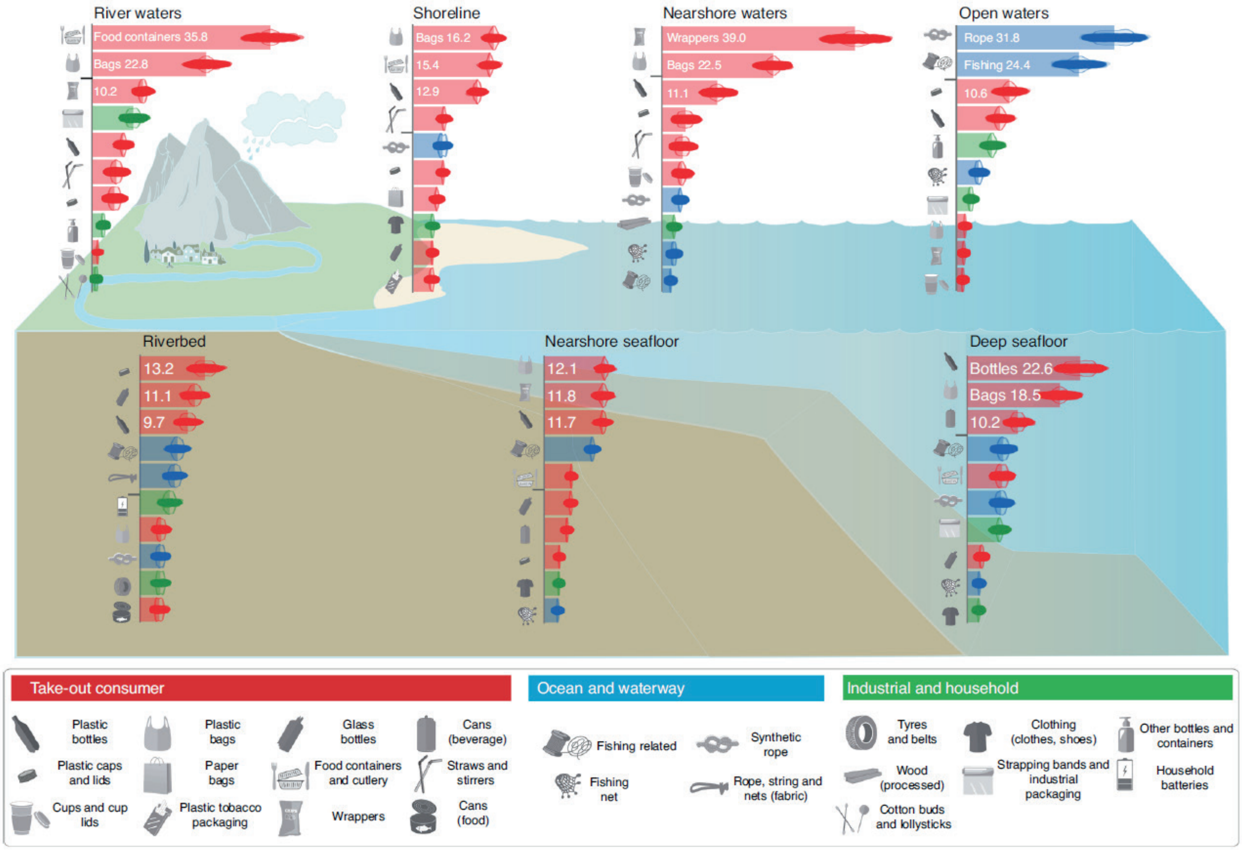


Fig 3.1. Top ten litter items in aquatic environments Bars show mean percentages per environment, while the darker-coloured areas and lines around the means show the individual data outputs (n = 10,000) and the distribution beanplot, respectively. Uncertainties of results were quantified through 10,000 Monte Carlo iterations in each environment. Bar colour relates to potential origin (take-out consumer, industrial and household, ocean and waterways). Items above the horizontal line marks in the rankings comprise, at least, 50% of the total items identified (Morales-Caselles et al., 2021)..

High abundances of FML (especially macrolitter) are also found in coastal waters, particularly in regions with high coastal populations, inadequate litter collection and management, and high levels of coastal tourism. Indeed, a large share (66.8%) of all FML released into the marine environment since the 1950s is stranded on the world's shorelines (Lebreton et al., 2019).

Several studies have attempted to quantify marine litter inputs into the marine environment and sources, yet high uncertainty exists about how much FML leaks into the ocean. Pew Charitable Trusts and SYSTEMIQ (2020) estimate that 11 million metric tonnes of plastic entered the ocean from land in 2016, of which half would float initially (UNEP and GRID-Arendal, 2016). Eriksen et al., 2014 estimated that 70% by weight of floating macro litter in the open ocean is fishing-related. However, the whole picture is still fragmented. The lack of empirical data in most oceans, the difficulty on determining the sources and the amounts of marine litter inputs, and the variety of methodologies applied for reporting FML hampers the global estimates of FML abundance and distribution (Haarr et al., 2022; Van Sebille et al., 2020; United Nations Environmental Programme et al., 2021).

Fig 3.2. Litter windrow likely associated to internal wave off Honduras (photo by C. Power) (top). Small patches and scattered litter arranged in bands by Langmuir circulation in southwestern Mediterranean (photo by A. Cózar) (bottom). Convergence bands perpendicular to wave lines are highlighted. (Cózar et al., 2021)

PHYSICAL CHARACTERISTICS OF FLOATING MARINE LITTER

FML items vary widely in terms of size, shape or composition. Besides, they are also affected by mechanisms of degradation, fragmentation, and biotic interaction, which altogether alter their buoyancy. The physical characteristics and transformation processes need to be accounted for whenever possible since together with the metocean conditions, they control the transport and distribution of FML in the marine environment (GESAMP, 2019).

Size

FML comes in all sizes, from larger objects of metres in length (e.g., wooden pallets) to medium and small sized objects of less than one metre (e.g., plastic bags and bottles), including plastic spheres, filaments or fragments on the scale of millimetres (e.g., textile fibres) (UNEP and GRID-Arendal, 2016). Observations of the size distribution of FML conducted by Cózar et al., 2014 pointed at important size-selective sinks, which removed millimetre-sized floating fragments on a large scale. The size can also affect the transport rate for larger items, which can drift faster due to inertial effects (Calvert et al., 2021). Overall, FML is classified into microlitter (size<5 mm), mesolitter (size 0.5–2.5 cm), and macrolitter (size>2.5 cm) categories. However, there is no community-wide agreement on where the boundaries between these categories lie (Van Sebille et al., 2020). Indeed, surveys differ in terms of the size classes of litter items, e.g., the Marine Strategy Framework Directive (MSFD) guidelines recommend to survey macrolitter items with a minimum length of 2.5 cm. In other protocols, litter size classes include items from 0-2.5 cm (Addamo et al., 2017). In this thesis, the categorization proposed by the MSFD is followed in order to adopt a consistent approach with the European monitoring frameworks (Galgani et al., 2013) (Table 3.1).

Composition

FML comprises a variety of material types (e.g., plastics, glass, metal, paper, cloth, rubber, and wood). However, the vast majority consists of plastics (on average 80% considering all environmental component (Morales-Caselles et al., 2021), accounting for up to 100 % of FML in some areas (Galgani et al., 2015). Plastic items made of polystyrene (PS) (e.g., cups), polyethylene (PE) (e.g., plastic bags) or polypropylene (PP) (e.g., bottle caps) would be expected to float in seawater and they are among the most abundant materials in the marine environment (Fig 3.3). Indeed, the estimated mass of PP, PE, and PS microplastics of 32-651μm size class suspended in the top 200 metres of the Atlantic Ocean is 11.6-21.1 million tonnes (Pabortsava and Lampitt 2020).

Shape

Some FML items, as bottles, could be designed in shapes suitable to trap air and float even though their polymeric density is higher than seawater (Miliute-Plepiene et al., 2018). Therefore, shape is also crucial for FML behaviour at sea. However, there is currently no standardized scheme for shape characterization although five general categories are recommended for the microlitter fraction of FML: 1) fragments or irregular shaped particles; 2) Near-spherical spherical foam particles; 3) films/ sheets; 4) fibres/ filaments; and 5) resin pellets, nurdles (GESAMP, 2019).

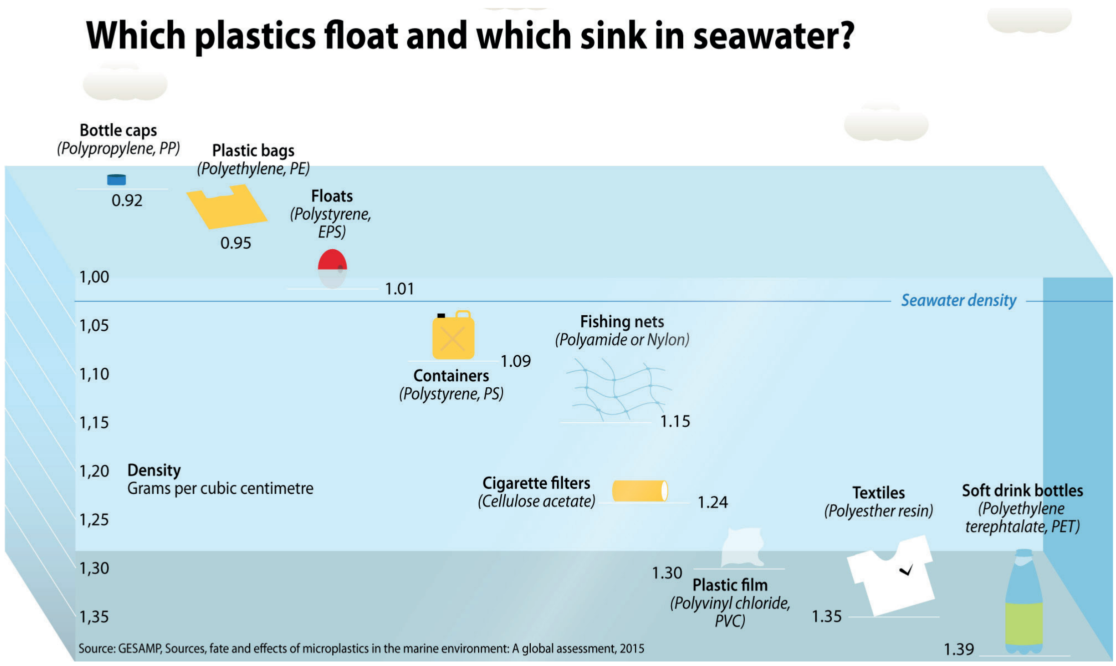


Fig 3.3. Common FML items together with their tendency to float or sink in the aquatic environment, based on density difference (UNEP and GRID-Arendal, 2016).

Buoyancy

Buoyancy is the ability of an object to float in water and it is intimately related to the combination of composition, size, and shape. The buoyancy determines the exposure of FML items to wind effect which directly affects litter transport in addition to the advection of ocean currents (Ko et al., 2020). Indeed, high buoyant items (e.g., bottles) may drift faster influenced by winds and currents contrary to heavier floating items (e.g., wooden pallets) primarily driven by currents (NOAA, 2016). The buoyancy of an object is normally assumed to be constant but can vary significantly on the marine environment with time when biofouled, because of the increased density (Fazey and Ryan, 2016; Kooi et al., 2017).

SURFACE TRANSPORT MECHANISMS OF FLOATING MARINE LITTER

FML transport reflects the well-known surface ocean circulation characterised by a broad pattern of ocean processes. At global scale, the ocean circulation is driven by winds, the Coriolis force, the density differences of temperature and salinity, and the deep-water formation in the Arctic and sub-Arctic seas and Southern Ocean (Lozier, 2015).

Field descriptor	Relative size	Common size divisions	Measurement units	References	Alternative options	Remarks
Mega	Very large	> 1 m	Metres	GESAMP		
Macro	Large	25 – 1000 mm	Metres Centimetres Millimetres	MSFD	25 – 50 mm	
Meso	Medium	5 – 25 mm	Centimetres Millimetres	MSFD	< 25 mm 1 – 25 mm	MARPOL Annex V (pre revision)
Micro	Small	< 5 mm	Millimetres Microns	NOWPAP MSFD	1 – 5 mm < 1 mm > 330 µm*	Eriksen *et al.* (2014)
Nano§	Extremely small	< 1 µm	Nanometres		< 100 nm	Not considered for monitoring

*operationally-defined, referring to the typical mesh size of 330 µm of towed plankton nets; §nano-sized particles can only be identified under carefully controlled laboratory conditions and may form a monolayer on one (plates) or two (fibres) dimensions

Table 3.1. Size categories of plastic marine litter, assuming a near-spherical form, showing common definitions and alternative options that may be appropriate for operational reasons (GESAMP, 2019)

The combination between the wind and the Coriolis force generates a rotation pattern in the upper layers of the ocean called the Ekman spiral, favouring water transport with a mean current called Ekman drift. The Ekman transport generates regions of surface convergence, as the subtropical gyres, where FML tends to accumulate, but also divergence areas with lower concentrations of FML (Van Sebille et al., 2020).

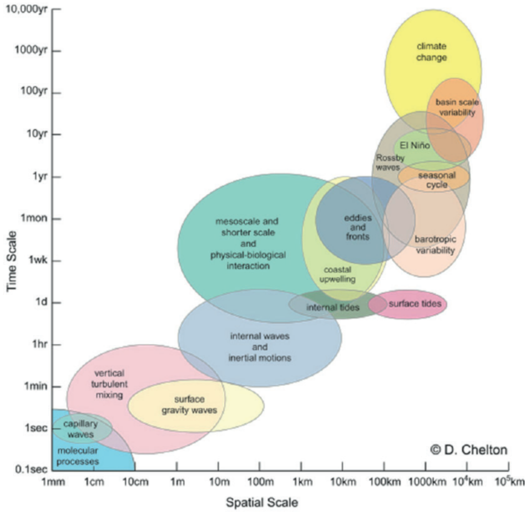


Fig 3.4. Time and space scales of ocean variability (courtesy D. Chelton, Oregon State University, after Dickey (2001))

Other coherent structures as the ocean mesoscale eddies and gyres, particularly, those which flow clockwise in the Northern Hemisphere, can also concentrate and transport FML over long distances (Brach et al., 2018; Falcón, 2021). Although more complex, the open ocean Stokes drift derived from water waves can induce FML transport, particularly for large objects (Calvert et al., 2021; Dobler et al., 2019) (Fig 3.4, 3.5). Large and highly buoyant objects are also subjected to the direct effect of wind ("windage"), and they can be transported faster compared to less buoyant and smaller FML items (Ko et al., 2020; Onink et al., 2021) (Fig 3.6).

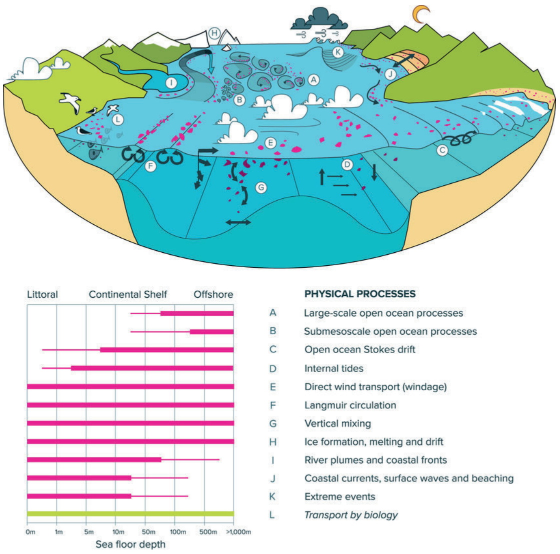


Fig 3.5. Schematic of the physical processes that affect the transport of plastic (pink items) in the ocean (top panel). The table (lower panel) identifies in which regions different processes are important (Van Sebille et al., 2020)

Besides windage, the wind-induced Langmuir cells can have a significant impact on the accumulation patterns of FML and planktonic organism, leading the formation of converge zones based on coherent roll structures (Gove et al., 2019). At the coastal area, internal waves originated by tides capture FML (Shanks, 2021) contrary to open ocean, where accumulation areas of FML are not related to tides (Sterl et al., 2020). FML can also accumulate at convergence lines associated with large salinity gradients at the fronts between the river plumes and the ambient sea (Korshenko et al., 2020). Shore exchange and FML transport can be enhanced by nearshore currents including alongshore currents and rip currents (Forsberg et al., 2020). Lastly, FML transport and distribution can be also influenced by processes such as vertical transport and mixing, ice formation and melting and extreme events (e.g., floods and tsunamis) (Van Sebille et al., 2020).

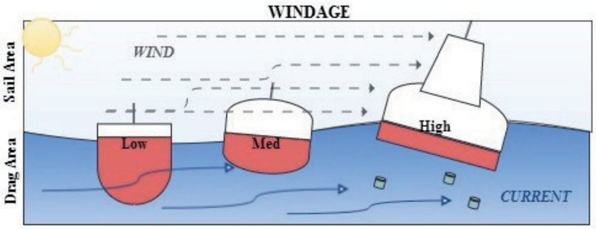


Fig 3.6. Varying degrees of windage on example floats. Image originally appeared in NOAA Marine Debris documents about Tsunami Debris trajectories (https://marinedebris.noaa.gov/japan-tsunami-marine-debris/modeling-movement-tsunami-debris) .

NUMERICAL MODELLING FOR SIMULATING FLOATING MARINE LITTER

Ocean circulation models can help to predict FML pathways and 'hotspots' and to identify potential sources of FML, filling the gaps in the origin and distribution when observations are not available (GESAMP, 2019; NOAA, 2016). These models provide the surface currents used to simulate FML transport and, through a process called data assimilation, they are updated with satellite and in situ measurements (e.g, by using drifters) in near-real time (NOAA, 2016). The surface current velocities are obtained for points or nodes on a discrete Eulerian grid over a series of time steps, and they are coupled to wind data and particle tracking models to simulate the movement of FML. Two particle tracking techniques can be used to calculate the trajectory of FML: (1) the Eulerian approach, when particles advected by surface currents are described in terms of their mass or volume concentrations at every Eulerian grid point and at each time step and (2) the Lagrangian approach, which focus on individual particle's trajectories carried along by currents over the time (Mountford and Morales Maqueda, 2019; van Sebille et al., 2018). Particle tracking models may incorporate additional factors such as movement resulting from the buoyancy of the item or a random motion component (turbulent diffusion) (NOAA, 2016).

Global ocean circulations models have been used for example to identify the concentration areas for FML in the sub-tropical gyres resulting from long-term mean circulation patterns (Lebreton et al., 2012) or to forecast the possible pathways and destiny of the FML derived from the Great Japan Tsunami of 2011 (Maximenko et al., 2012). However, these global models are not able to represent small-scale oceanic processes, such as sub-mesoscale eddies, nor do they model coastal processes, such as tides, freshwaters, and estuarine circulation (NOAA, 2016). Higher resolution models have enabled researchers to simulate FML transport at basin scale in the Adriatic Sea (Carlson et al., 2017), in the Ionian Sea (Politikos et al., 2020) and in the transboundary waters of the Mediterranean Sea (Macias et al., 2022) (Fig 3.7).

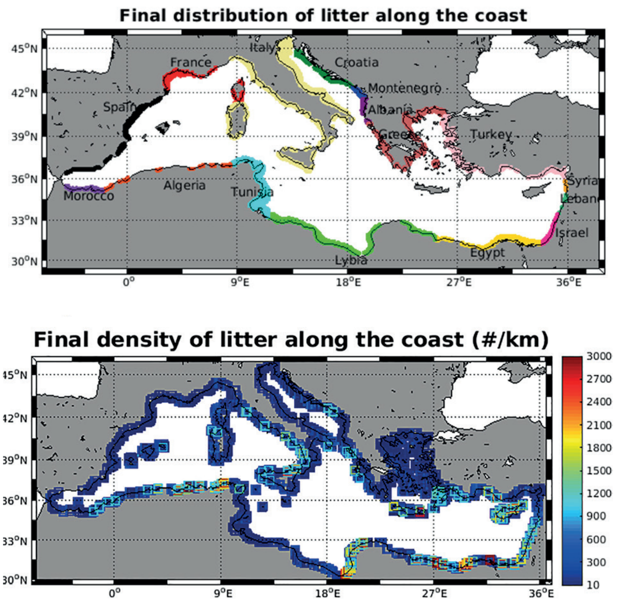


Fig 3.7. Example of FML modelling in transboundary waters for the Mediterranean Sea. Position of the particles in the initial time step (i.e., the chronological end) of the simulations. Homogeneous litter distribution in the shallow regions. Colours correspond to the different countries indicated in the map (top). Non-homogeneous litter distribution. The colour-scale indicates the density of particles per lineal km of coast (bottom) (Macias et al., 2021).

In The Black Sea, dataset of FML from visual ship observations have also allowed to validate modelling results provided by a mesoscale circulation model coupled with a particle tracking model (Miladinova et al., 2020). Though, research on FML behaviour at regional scale and in the coastal environment is still in its early stage, and much has yet to be revealed. Further modelling efforts are necessary to better understand the behaviour of FML exposure to windage effect or the consequences of beaching and reflotation processes in the coastal accumulation of FML (Hardesty et al., 2017). Higher-resolution models nested within basin-scale or global models targeting specific areas could be useful for providing insights into even finer-scale patterns of FML accumulation or dispersion (NOAA, 2016). The reliability of model outputs will depend on a number of factors including the availability of representative data on the amounts of FML and sources considered (land or sea-based), the type of FML (e.g., size, buoyancy) and the coastal and ocean dynamics (Hardesty et al., 2017, NOAA 2016). Therefore, quantitative, and harmonised dataset derived from monitor FML is required for calibrating and validating modelling results.

POLICY-RELEVANT FRAMEWORKS FOR MONITORING FLOATING MARINE LITTER

Nowadays, FML is being addressed internationally by the United Nations (UN) and by individual countries at national, subnational and regional levels. While none of the Sustainable Development Goals (SDG) is fully devoted to litter, FML is directly included in SDG 14.1 with the indicator 14.1.1 that aims to measure floating plastic litter density as a global indicator of marine pollution (UNEP, 2022).The evaluation of the effectiveness (including enforcement) of existing policy and regulatory frameworks for prevent, reduce and control marine litter pollution is supported by the development and application of this type of indicators (Basel Convention, 2013). They provide valuable information about the state of the marine environment by means of a regular and standardized monitoring of FML. Besides the UN, the Regional Seas Action Plans also consider FML monitoring for implementing detailed and extended actions on marine pollution.

At European level, the Barcelona Conventions developed the “Integrated Monitoring and Assessment Programme of the Mediterranean Sea (IMAP)” for supporting FML management based on the trends in the amount of litter provided by the Indicator 23 (UN/MAP, 2017). The MSFD also considers monitoring FML quantities and distribution through the Descriptor 10 to assess the Good Environmental Status (GES) of the European marine environment (Galgani et al., 2013). Indeed, monitoring FML comprises different methodologies for gathering representative information on marine litter pollution.

The most common sampling method to collect floating micro, meso and (to a limited extent) macrolitter is the surface net tow, using a neuston net, manta trawl or mega traw (GESAMP, 2019) (Fig 3.8). Bulk water sampling can be also appropriate to collect microlitter at sea surface. Lastly, visual observations from ships, photographic and aerial surveys from an airplanes or drones and remote sensing from satellites are often conducted for monitoring larger items.

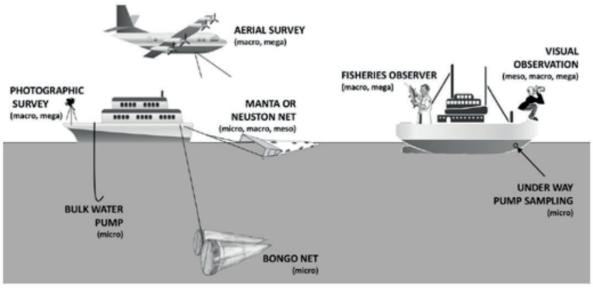


Fig 3.8. Schematic of possible methods used for sampling the sea surface and water column (image courtesy of Marcus Eriksen) (GESAMP, 2019).

TRANSBOUNDARY INITIATIVES TO TACKLE FLOATING MARINE LITTER

It is important to highlight that FML is a transboundary concern, particularly for land-sea transition zones (Krelling et al., 2017; Kao et al., 2021) and countries sharing sea and river basins (Hatzonikolakis et al., 2022). This requires multi-stakeholder cooperation for monitoring but also initiatives to prevent and mitigate FML in the shared waters. At global scale, most solutions to tackle litter pollution have targeted FML and they have been mainly tailored for macrolitter rather than meso or microlitter (Bellou et al., 2021). Unfortunately, the initiatives have left aside the transboundary nature of floating litter and only few regional agreements and projects offer effective actions at transboundary basin level. In the North-East Atlantic region, the OSPAR Convention has adopted the specific action 55 to investigate the behaviour of FML and understand where it is likely that accumulations or hotspots of litter may occur (OSPAR, 2014). In the Danube river, the Joint Action Plan developed by the International Commission for the Protection of the Rhine (ICPR) includes ratified measures to monitor litter pollution and it represents an example of transboundary management for preventing marine litter. In the Bay of Biscay, the LIFE LEMA project tackled FML in the transboundary waters between France and Spain by developing new tools and technologies to manage FML more efficiently (see https://www.lifelema.eu/en/the-project/ for details) (Fig 3.9). While prevention is key, more cooperation between countries and stakeholders is necessary for implementing effective litter monitoring and removal measures, particularly in FML hotspots and vulnerable areas (e.g., Marine Protected Areas).

THE BAY OF BISCAY: A REGIONAL HOTSPOT OF FLOATING MARINE LITTER

Nowadays, there are three regional relevant hotspots of marine litter at global scale of great concern due to their potential long-term and large-scale risk for ecosystem functioning and human health: (1) the Mediterranean Sea, due to its enclosed nature; (2) the Arctic Ocean, due to its pristine nature; and (3) the East Asia and Southeast Asian regions, due to a poor waste management system for a population highly dependent on the ocean resources (UNEP, 2021). At European level, the attention to marine pollution, and particularly, to FML has grown for semi-enclosed seas as the Baltic Sea (Rothäusler et al., 2019) or the Black Sea (Stanev and Ricker, 2019), but also for other seas. Over the past few years, global studies coupling ocean circulation and Lagrangian particle tracking models reported that the Bay of Biscay is a hotspot for both land-based and sea-based sources of marine litter (Lebreton et al., 2012; van Sebille et al., 2012). Differences in coastal retention periods and beaching have been also observed when windage effect is accounted when modelling FML transport. Rodríguez-Díaz et al., 2020 showed that highly floating macrolitter, strongly driven by winds, accumulate in nearshore areas of the Bay of Biscay or end up beached while microlitter tends to disperse oceanward. According to field investigations conducted up to date, the Bay of Biscay presents a medium level of microplastic pollution (Mendoza et al., 2020) and one of the main sources of seems to be linked to fishing activities, major shipping lanes and river discharges (van den Beld et al., 2017).

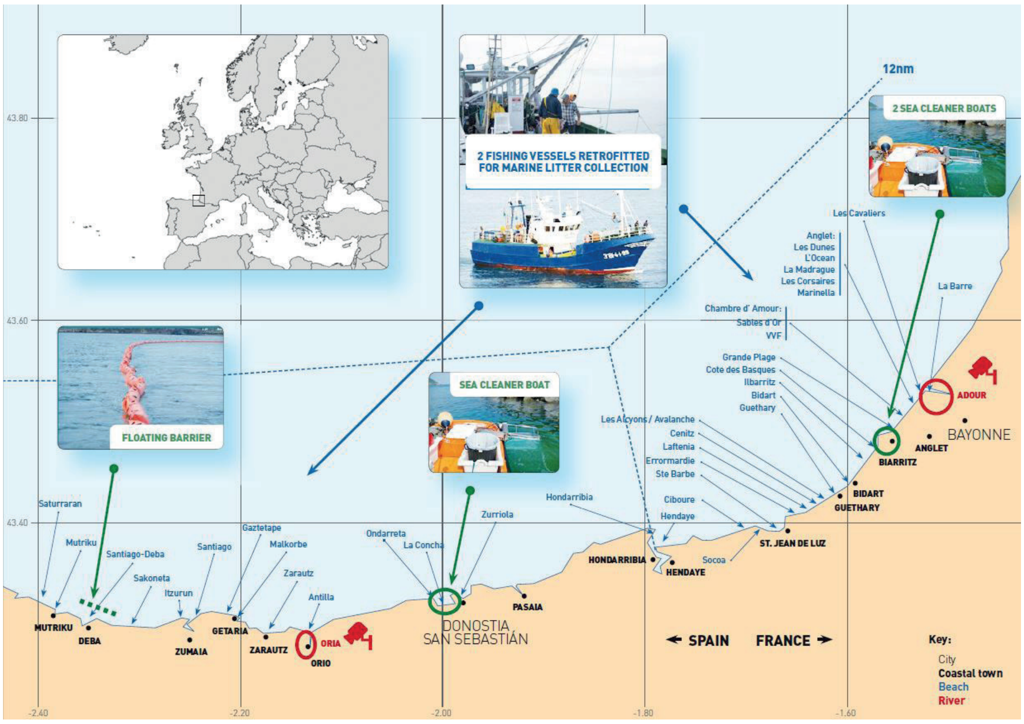


Fig 3.9. LIFE LEMA project area, collection effort distribution and new technologies deployment (https://www.lifelema.eu/en/)

The seasonal circulation patterns, particularly in the south-east Bay of Biscay, tend to generate a high retention for FML during spring and summer and longer residence times and higher concentrations in winter influenced by the run-offs and the influx of FML from local but also from distant sources (Pereiro et al., 2019; Rubio et al., 2020; Declerck et al., 2019). Since 2003, local authorities from the south-east Bay of Biscay have supported during high retention periods (e.g., spring and summer) active practices of fishing FML where fishermen involved are paid (Basurko et al., 2015; Pınarbaşı et al., 2020). Between 2016 and 2019, they coordinated and participated in LIFE LEMA project to define an optimized solution to manage FML in the area. Thanks to LIFE LEMA, and subsequently, to FML-TRACK project empowered by the Copernicus Marine Service, active fishing for FML and beach clean-up activities are now supported with innovative detection and tracking solutions combining ocean modelling and remote observation systems (Delpey et al., 2021). However, precise knowledge about quantities, composition, sources, and pathways is still limited, and more modelling and monitoring efforts regarding FML are necessary to get er picture of how FML is transported, accumulated, and distributed within the Bay of Biscay.

References

Addamo, A. M., Laroche, P., and Hanke, G.: Top marine beach litter items in Europe, Publ. Off. Eur. Union Luxembg., 2017.

Al-Khayat, J. A., Veerasingam, S., Aboobacker, V. M., and Vethamony, P.: Hitchhiking of encrusting organisms on floating marine debris along the west coast of Qatar, Arabian/Persian Gulf, Sci. Total Environ., 776, 145985, https://doi.org/10.1016/J.SCITOTENV.2021.145985, 2021.

Basel Convention: Framework for the environmentally sound management of hazardous wastes and other wastes (UNEP/CHW.11/3/Add.1/Rev.1), http://www.basel.int/Implementation/%0ACountryLedInitiative/EnvironmentallySoundManagement/%0AESMFramework/tabid/3616/Default.aspx, 2013.

Basurko, O. C., Gabiña, G., Andrés, M., Rubio, A., Uriarte, A., and Krug, I.: Fishing for floating marine litter in SE Bay of Biscay: Review and feasibility study, Mar. Policy, 61, 103–112, https://doi.org/https://doi.org/10.1016/j.marpol.2015.07.010, 2015.

van den Beld, I. M. J., Guillaumont, B., Menot, L., Bayle, C., Arnaud-Haond, S., and Bourillet, J.-F.: Marine litter in submarine canyons of the Bay of Biscay, Deep Sea Res. Part II Top. Stud. Oceanogr., 145, 142–152, https://doi.org/https://doi.org/10.1016/j.dsr2.2016.04.013, 2017.

Bellou, N., Gambardella, C., Karantzalos, K., Monteiro, J. G., Canning-Clode, J., Kemna, S., Arrieta-Giron, C. A., and Lemmen, C.: Global assessment of innovative solutions to tackle marine litter, Nat. Sustain., 4, 516–524, https://doi.org/10.1038/s41893-021-00726-2, 2021.

Bigdeli, M., Mohammadian, A., Pilechi, A., and Taheri, M.: Lagrangian Modeling of Marine Microplastics Fate and Transport: The State of the Science, J. Mar. Sci. Eng., 10, https://doi.org/10.3390/jmse10040481, 2022.

Brach, L., Deixonne, P., Bernard, M.-F., Durand, E., Desjean, M.-C., Perez, E., van Sebille, E., and ter Halle, A.: Anticyclonic eddies increase accumulation of microplastic in the North Atlantic subtropical gyre, Mar. Pollut. Bull., 126, 191–196, https://doi.org/https://doi.org/10.1016/j.marpolbul.2017.10.077, 2018.

Calvert, R., McAllister, M. L., Whittaker, C., Raby, A., Borthwick, A. G. L., and van den Bremer, T. S.: A mechanism for the increased wave-induced drift of floating marine litter, J. Fluid Mech., 915, A73, https://doi.org/DOI: 10.1017/jfm.2021.72, 2021.

Carlson, D. F., Suaria, G., Aliani, S., Fredj, E., Fortibuoni, T., Griffa, A., Russo, A., and Melli, V.: Combining Litter Observations with a Regional Ocean Model to Identify Sources and Sinks of Floating Debris in a Semi-enclosed Basin: The Adriatic Sea, Front. Mar. Sci., 4, https://doi.org/10.3389/fmars.2017.00078, 2017.

Carpenter, E. J., Anderson, S. J., Harvey, G. R., Miklas, H. P., and Peck, B. B.: Polystyrene spherules in coastal waters, Science (80-.)., 178, 749–750, 1972.

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., and Duarte, C. M.: Plastic debris in the open ocean, Proc. Natl. Acad. Sci., 111, 10239–10244, https://doi.org/10.1073/pnas.1314705111, 2014.

Cózar, A., Aliani, S., Basurko, O. C., Arias, M., Isobe, A., Topouzelis, K., Rubio, A., and Morales-Caselles, C.: Marine Litter Windrows: A Strategic Target to Understand and Manage the Ocean Plastic Pollution, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.571796, 2021.

Declerck, A., Delpey, M., Rubio, A., Ferrer, L., Basurko, O. C., Mader, J., and Louzao, M.: Transport of floating marine litter in the coastal area of the south-eastern Bay of Biscay: A Lagrangian approach using modelling and observations, J. Oper. Oceanogr., 1–15, https://doi.org/10.1080/1755876x.2019.1611708, 2019.

Dobler, D., Huck, T., Maes, C., Grima, N., Blanke, B., Martinez, E., and Ardhuin, F.: Large impact of Stokes drift on the fate of surface floating debris in the South Indian Basin, Mar. Pollut. Bull., 148, 202–209, https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.07.057, 2019.

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., and Reisser, J.: Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea, PLoS One, 9, e111913, https://doi.org/10.1371/journal.pone.0111913, 2014.

Falcón, M. de B.: Mesoscale eddies and plastic dispersion, Utrecht University, 2021.

Fazey, F. M. C. and Ryan, P. G.: Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity, Environ. Pollut., 210, 354–360, https://doi.org/10.1016/J.ENVPOL.2016.01.026, 2016.

Forsberg, P. L., Sous, D., Stocchino, A., and Chemin, R.: Behaviour of plastic litter in nearshore waters: First insights from wind and wave laboratory experiments, Mar. Pollut. Bull., 153, https://doi.org/10.1016/j.marpolbul.2020.111023, 2020.

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

Galgani, F., Hanke, G., and Maes, T.: Global Distribution, Composition and Abundance of Marine Litter, in: Marine Anthropogenic Litter, edited by: Bergmann, M., Gutow, L., and Klages, M., Springer International Publishing, Cham, 29–56, https://doi.org/10.1007/978-3-319-16510-3_2, 2015.

GESAMP: Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean, Journal Series GESAMP Reports and Studies, 123 pp., 2019.

GESAMP: Sea-based sources of marine litter, GESAMP Reports & Studies Series, (Gilardi, K., ed.), 8–109 pp., 2021.

Gove, J. M., Whitney, J. L., McManus, M. A., Lecky, J., Carvalho, F. C., Lynch, J. M., Li, J., Neubauer, P., Smith, K. A., Phipps, J. E., Kobayashi, D. R., Balagso, K. B., Contreras, E. A., Manuel, M. E., Merrifield, M. A., Polovina, J. J., Asner, G. P., Maynard, J. A., and Williams, G. J.: Prey-size plastics are invading larval fish nurseries, Proc. Natl. Acad. Sci., 116, 24143–24149, https://doi.org/10.1073/pnas.1907496116, 2019.

Haarr, M. L., Falk-Andersson, J., and Fabres, J.: Global marine litter research 2015–2020: Geographical and methodological trends, Sci. Total Environ., 820, 153162, https://doi.org/10.1016/J.SCITOTENV.2022.153162, 2022.

Hardesty, B. D., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., van Sebille, E., Vethaak, A. D., and Wilcox, C.: Using Numerical Model Simulations to Improve the Understanding of Micro-plastic Distribution and Pathways in the Marine Environment, Front. Mar. Sci., 4, https://doi.org/10.3389/fmars.2017.00030, 2017.

Hatzonikolakis, Y., Giakoumi, S., Raitsos, D. E., Tsiaras, K., Kalaroni, S., Triantaphyllidis, G., and Triantafyllou, G.: Quantifying Transboundary Plastic Pollution in Marine Protected Areas Across the Mediterranean Sea , https://www.frontiersin.org/article/10.3389/fmars.2021.762235, 2022.

Kao, J.-C., Cho, C.-C., and Kao, R.-H.: A Study on Transboundary Marine Governance of Floating Marine Debris—Taking Kinmen–Xiamen Waters between China and Taiwan as an Example, 13, https://doi.org/10.3390/su132414063, 2021.

Ko, C.-Y., Hsin, Y.-C., and Jeng, M.-S.: Global distribution and cleanup opportunities for macro ocean litter: a quarter century of accumulation dynamics under windage effects, Environ. Res. Lett., 15, 104063, https://doi.org/10.1088/1748-9326/abae29, 2020.

Kooi, M., Nes, E. H. van, Scheffer, M., and Koelmans, A. A.: Ups and Downs in the Ocean: Effects of Biofouling on Vertical Transport of Microplastics, Environ. Sci. Technol., 51, 7963–7971, https://doi.org/10.1021/acs.est.6b04702, 2017.

Korshenko, E., Zhurbas, V., Osadchiev, A., and Belyakova, P.: Fate of river-borne floating litter during the flooding event in the northeastern part of the Black Sea in October 2018, Mar. Pollut. Bull., 160, 111678, https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111678, 2020.

Krelling, A. P., Souza, M. M., Williams, A. T., and Turra, A.: Transboundary movement of marine litter in an estuarine gradient: Evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates, Mar. Pollut. Bull., 119, 48–63, https://doi.org/10.1016/J.MARPOLBUL.2017.03.034, 2017.

Lambert, C., Authier, M., Dorémus, G., Laran, S., Panigada, S., Spitz, J., Van Canneyt, O., and Ridoux, V.: Setting the scene for Mediterranean litterscape management: The first basin-scale quantification and mapping of floating marine debris, Environ. Pollut., 263, 114430, https://doi.org/https://doi.org/10.1016/j.envpol.2020.114430, 2020.

Lavers, J. L., Dicks, L., Dicks, M. R., and Finger, A.: Significant plastic accumulation on the Cocos (Keeling) Islands, Australia, Sci. Rep., 9, 7102, https://doi.org/10.1038/s41598-019-43375-4, 2019.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., and Reisser, J.: Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic, Sci. Rep., 8, 4666, https://doi.org/10.1038/s41598-018-22939-w, 2018.

Lebreton, L., Egger, M., and Slat, B.: A global mass budget for positively buoyant macroplastic debris in the ocean, Sci. Rep., 9, 1, 2019.

Lebreton, L. C. M., Greer, S. D., and Borrero, J. C.: Numerical modelling of floating debris in the world's oceans, Mar. Pollut. Bull., 64, 653–661, https://doi.org/https://doi.org/10.1016/j.marpolbul.2011.10.027, 2012.

Lozier, M.: Overturning Assumptions: Past, present, and future concerns about the ocean's circulation, 25, 240–251, https://doi.org/10.5670/oceanog.2015.50, 2015.

Macias, D., Stips, A., and Hanke, G.: Model based estimate of transboundary litter pollution on Mediterranean coasts, Mar. Pollut. Bull., 113121, https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.113121, 2021.

Macias, D., Stips, A., and Hanke, G.: Model based estimate of transboundary litter pollution on Mediterranean coasts, Mar. Pollut. Bull., 175, 113121, https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.113121, 2022.

Maximenko, N., Hafner, J., and Niiler, P.: Pathways of marine debris derived from trajectories of Lagrangian drifters, Mar. Pollut. Bull., 65, 51–62, 2012.

Mendoza, A., Osa, J. L., Basurko, O. C., Rubio, A., Santos, M., Gago, J., Galgani, F., and Peña-Rodriguez, C.: Microplastics in the Bay of Biscay: An overview, Mar. Pollut. Bull., 153, 110996, https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.110996, 2020.

Miladinova, S., Macias, D., Stips, A., and Garcia-Gorriz, E.: Identifying distribution and accumulation patterns of floating marine debris in the Black Sea, Mar. Pollut. Bull., 153, 110964, https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.110964, 2020.

Miliute-Plepiene, J., Fråne, A., Haikonen, K., and Youhanan, L.: Overview of available methods to monitor marine plastic litter Incl. method for riverine litter monitoring developed within BLASTIC, 2018.

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J. I., Montero, E., Arroyo, G. M., Hanke, G., Salvo, V. S., Basurko, O. C., Mallos, N., Lebreton, L., Echevarría, F., van Emmerik, T., Duarte, C. M., Gálvez, J. A., van Sebille, E., Galgani, F., García, C. M., Ross, P. S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., and Cózar, A.: An inshore–offshore sorting system revealed from global classification of ocean litter, Nat. Sustain., 4, 484–493, https://doi.org/10.1038/s41893-021-00720-8, 2021.

Mountford, A. S. and Morales Maqueda, M. A.: Eulerian modelling of the three-dimensional distribution of seven popular plastic types in the global ocean, J. Geophys. Res. Ocean., 124, 8558, 2019.

NOAA: Modeling Oceanic Transport of Floating Marine Debris, National Oceanic and Atmospheric Administration Marine Debris Program, 21 pp., 2016.

OSPAR: Marine Litter Regional Action Plan , 2014.

Pereiro, D., Souto, C., and Gago, J.: Dynamics of floating marine debris in the northern Iberian waters: A model approach, J. Sea Res., 144, 57–66, https://doi.org/https://doi.org/10.1016/j.seares.2018.11.007, 2019.

Pınarbaşı, K., Galparsoro, I., Alloncle, N., Quemmerais, F., and Borja, Á.: Key issues for a transboundary and ecosystem-based maritime spatial planning in the Bay of Biscay, Mar. Policy, 120, 104131, https://doi.org/https://doi.org/10.1016/j.marpol.2020.104131, 2020.

Pogojeva, M., Zhdanov, I., Berezina, A., Lapenkov, A., Kosmach, D., Osadchiev, A., Hanke, G., Semiletov, I., and Yakushev, E.: Distribution of floating marine macro-litter in relation to oceanographic characteristics in the Russian Arctic Seas, Mar. Pollut. Bull., 166, 112201, https://doi.org/10.1016/J.MARPOLBUL.2021.112201, 2021.

Politikos, D. V, Tsiaras, K., Papatheodorou, G., and Anastasopoulou, A.: Modeling of floating marine litter originated from the Eastern Ionian Sea: Transport, residence time and connectivity, Mar. Pollut. Bull., 150, 110727, https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.110727, 2020.

Rodríguez-Díaz, L., Gómez-Gesteira, J. L., Costoya, X., Gómez-Gesteira, M., and Gago, J.: The Bay of Biscay as a trapping zone for exogenous plastics of different sizes, J. Sea Res., 163, 101929, https://doi.org/https://doi.org/10.1016/j.seares.2020.101929, 2020.

Rothäusler, E., Jormalainen, V., Gutow, L., and Thiel, M.: Low abundance of floating marine debris in the northern Baltic Sea, Mar. Pollut. Bull., 149, https://doi.org/10.1016/j.marpolbul.2019.110522, 2019.

Rubio, A., Hernández-Carrasco, I., Orfila, A., González, M., Reyes, E., Corgnati, L., Berta, M., Griffa, A., and Mader, J.: A Lagrangian approach to monitor local particle retention conditions in coastal areas, J. Oper. Oceanogr., 13:sup1, https://doi.org/10.1080/1755876X.2020.1785097, 2020.

van Sebille, E., England, M. H., and Froyland, G.: Origin, dynamics and evolution of ocean garbage patches from observed surface drifters, Environ. Res. Lett., 7, 44040, https://doi.org/10.1088/1748-9326/7/4/044040, 2012.

van Sebille, E., Griffies, S. M., Abernathey, R., Adams, T. P., Berloff, P., Biastoch, A., Blanke, B., Chassignet, E. P., Cheng, Y., Cotter, C. J., Deleersnijder, E., Döös, K., Drake, H. F., Drijfhout, S., Gary, S. F., Heemink, A. W., Kjellsson, J., Koszalka, I. M., Lange, M., Lique, C., MacGilchrist, G. A., Marsh, R., Mayorga Adame, C. G., McAdam, R., Nencioli, F., Paris, C. B., Piggott, M. D., Polton, J. A., Rühs, S., Shah, S. H. A. M., Thomas, M. D., Wang, J., Wolfram, P. J., Zanna, L., and Zika, J. D.: Lagrangian ocean analysis: Fundamentals and practices, Ocean Model., 121, 49–75, https://doi.org/https://doi.org/10.1016/j.ocemod.2017.11.008, 2018.

Van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J. M., Bagaev, A., Bergmann, M., Chapron, B., Chubarenko, I., and Cózar, A.: The physical oceanography of the transport of floating marine debris, Environ. Res. Lett., 15, 23003, 2020.

Shanks, A. L.: Observational Evidence and Open Questions on the Role of Internal Tidal Waves on the Concentration and Transport of Floating Plastic Debris, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.621062, 2021.

Stanev, E. V and Ricker, M.: The Fate of Marine Litter in Semi-Enclosed Seas: A Case Study of the Black Sea, Front. Mar. Sci., 6, https://doi.org/10.3389/fmars.2019.00660, 2019.

Sterl, M. F., Delandmeter, P., and van Sebille, E.: Influence of Barotropic Tidal Currents on Transport and Accumulation of Floating Microplastics in the Global Open Ocean, J. Geophys. Res. Ocean., 125, e2019JC015583, https://doi.org/https://doi.org/10.1029/2019JC015583, 2020.

UN/MAP: 2017 Mediterranean Quality Status Report, Mediterranean Action Plan Barcelona Convention, 539 pp., 2017.

UNEP: From pollution to solution, From Pollution to Solution: A global assessment of marine litter and plastic pollution, Nairobi, Kenya, https://doi.org/10.1016/S0262-4079(18)30486-X, 2021.

UNEP: Addressing marine litter and microplastics. UN system-wide contributions. A Synthesis Report by the United Nations Environment Management Group, 2022.

UNEP and GRID-Arendal: Marine Litter Vital Graphics., United Nations Environment Programme and GRID-Arendal, Nairobi and Arendal, 2016.

United Nations Environmental Programme, Secretariats of the Basel, Secretariats, R. and S., and Grid-Arendal: Drowning in Plastics: Marine Litter and Plastic Waste Vital Graphics, 2021.

4

OBJECTIVES, HYPOTHESIS AND THESIS STRUCTURE

OBJECTIVES

The general objective of this thesis is to improve the knowledge on the abundance, composition, distribution and fate of floating litter in the south-eastern Bay of Biscay based on met-ocean historical data, visual observations of FML, surface sampling, drifters observations, and Lagrangian modelling techniques. The outcomes of this thesis provide key data and facts to assess the state of FML in the area as well as information to outline prevention and mitigation measures at local and regional scale.

In order to fulfil the general objective, four specific objectives are set as follows:

Specific objective 1

Assess the abundance and distribution of FML in the Bay of Biscay combining surface observations from vessels and sampling in open ocean and coastal waters of the south-eastern Bay of Biscay (Chapters 1 and 2).

Specific objective 2

Study the convergence zones of FML in the south-east coast of the Bay of Biscay (so-called “marine litter windrows”) thanks to data collected during active fishing for litter activities to estimate their loads, composition, frequency, size and potential sources (Chapter 3).

Specific objective 3

Analyze the seasonal pathways and fate of FML originated from sea-based activities in the Bay of Biscay as well as the concentration within Marine Protected Areas combining met-ocean and fishing activity databases, Monte Carlo simulations and Lagrangian modelling (Chapter 4).

Specific objective 4

Analyze the seasonal pathways and fate of floating riverine litter transported through rivers to the south-east coast of the Bay of Biscay combining satellite-tracked observations provided by surface drifters, measurements of surface currents from high frequency radar systems and Lagrangian modelling (Chapter 5).

HYPOTHESIS

“*The south-eastern Bay of Biscay shows complex temporal and spatial abundances, distribution and transport patterns of floating marine litter. A better knowledge of those is key for implement preventive and mitigation management measures to reduce the level of litter pollution.*”

THESIS STRUCTURE

The PhD dissertation is arranged as follows:

Introduction

The purpose of this section is to introduce the context of this research work. The state of art is explained to establish the objectives and hypothesis of the presented thesis. Each chapter of the results section also includes an in-depth and tailored introduction on the topic addressed. To achieve the specific objectives defined above, results have been structured in five chapters and presented as scientific publications:

Chapter 1 - First assessment of floating marine litter abundance and distribution in the Bay of Biscay from an integrated ecosystem survey

This first contribution provides a jointly analysis of floating macro and microlitter abundance and distribution in the Bay of Biscay. Multiannual datasets were collected combining net tows and visual observations during integrated ecosystem surveys conducted from vessels devoted to monitor the environmental status of the regional marine waters. Results constitute a baseline for floating data collection in the Bay of Biscay and can be helpful to reliably detect spatial and temporal changes in floating marine litter.

Chapter 2 - The coastal waters of the south-east Bay of Biscay a dead-end for Neustonic plastics

The second contribution explores the multiannual variation of neustonic plastic abundance in the south-east coast of the Bay of Biscay. The collection was performed along sampling locations out of the common floating marine litter convergence zones. This allowed to address the sub-regional differences on litter occurrence between less and highly polluted surface compartments where accumulation structures emerge.

Chapter 3 - Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter

The third contribution provides an observational description of floating marine litter accumulation structures (“litter windrows”) in the south-east coast of the Bay of Biscay. Data gathered by a small-scale fishing vessel devoted to active fishing for FML activities revealed with unprecedent detail the general features of these litter windrows derived from submesoscale processes in the area..

Chapter 4 - Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas

This chapter together with Chapter 5 are focused on shedding light on the transport and distribution of FML originated by two main sources within the Bay of Biscay: rivers and fishing industry. In Chapter 4, the simulated trajectories fishing-related items according to their buoyancy provide insights into the seasonal distribution patterns of litter originated from sea-based sources in the Bay of Biscay. Results highlighted the behavioral differences between items and provide evidence of their accumulation at the coastal area and in Marine Protected Areas, useful to support medium to long-term strategies oriented to reduce the impact of fishing floating marine litter in the region.

Chapter 5 - Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas

At the last contribution, a seasonal comparison of floating riverine litter transport and fate released by the main rivers within the south-eastern Bay of Biscay is presented to complement the results obtained for fishing sources. The behaviour and concentration in the coastal area is provided according to the buoyancy of the items and based on simulations forced with currents measured by high-frequency radars and parametrizations derived from model calibration with drifters data. Results identified seasonally the regions in the area more likely to accumulate large quantities of riverine liter and the contribution per river, relevant to assist operations to control FML originated inland in short to medium-term and to identify the priority rivers for future monitoring programmes.

The Discussion and Conclusion sections have been also integrated to draw the main findings of the thesis in the context of previous research, establish the significance of the work, and the future lines of research.

5

RESULTS

CHAPTER 1

Publication data

Type	Baseline
Title	First assessment of floating marine litter abundance and distribution in the Bay of Biscay from an integrated ecosystem survey
Authors	Irene Ruiz, Iñaki Burgoa, María Santos, Oihane C.Basurko, Isabel García-Barón, Maite Louzao, Beatriz Beldarrain, Deniz Kukul, Claudia Valle, Ainhize Uriarte and Anna Rubio
Affiliation	AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Pasaia, Spain
Journal	Marine Pollution Bulletin
Year	2022
Volume	174
Stage of publication	Published

HIGHLIGHTS

01. A combined assessment of macro and microlitter was done for the Bay of Biscay
02. An average of 3.13 (macro) and 756,865 (micro) items/km2 were observed
03. Packaging, other plastic items and plastic bottles were the most abundant items
04. No correlation between densities and oceanographic variables was observed
05. Integrated ecosystem surveys are a good platform for monitoring marine litter

ABSTRACT

In the Bay of Biscay, regional monitoring programmes and data on abundance and distribution of floating marine litter are scarce, contrary to many other European marine regions. Here, a joint analysis of multiyear observations (2017-2019) of floating micro and macro litter and oceanographic conditions was conducted for the Bay of Biscay by combining microlitter samplings with neuston nets and vessel-based macrolitter observations. Results show spatiotemporal abundance and distribution patterns. The density of floating microlitter increased from 26,056 items/km2 in 2017 to 1,782,454 items/km2 in 2019; floating macrolitter densities barely varied amongst year (2.52 items/km2 in 2017 and 3.70 items/km2 in 2019). No significant correlation was found between densities of micro and macrolitter, neither for the oceanographic variables. We conclude that longer micro and macrolitter monitoring periods and standardized datasets based on the cross-border cooperation are needed to collect more comparable information, evaluate trends, and support decision making in the area.

KEY WORDS

Marine pollution; Floating marine litter; Plastic; Monitoring; Bay of Biscay

BASELINE

Marine litter monitoring programmes have become a valuable tool for governments, institutions, and organizations for decision-making. Particularly, they are useful to gain a better understanding of the sources and the dynamics of marine litter in the environment and to assess the effectiveness of prevention and mitigation policies and solutions. At global scale, the internationally agreed Sustainable Development Goal (SDG) indicator “Index of coastal eutrophication and floating plastic debris density” proposes to measure floating plastic litter by calculating the average count of plastic items per km2 derived from visual observation and net tows surveys (Smail et al., 2020;Walker, 2021). At European level, the Marine Strategy Framework Directive (MSFD, 2008/56/EC) sets indicators to ensure floating marine litter (FML hereafter) “do not cause harm to the coastal and marine environment” (Descriptor 10) and requires EU Member States to report their amount of micro and macrolitter per km2 including the analysis of its composition, spatial distribution and their source (Galgani et al., 2013a;Klein et al., 2017). Monitoring actions amongst different environmental compartments and member states requires the use of consistent and replicable sampling methodologies to assurance reliable up-to-date FML datasets. However, the different sampling approaches conducted so far have hampered data collection and comparison between different areas and over time (Galgani et al., 2015;Ryan, 2015;Kershaw et al., 2019).

Multiannual time series and surveys, which cover large areas or regional scales are scarce. This hinders the assessment of temporal trends and the connection between processes that shape FML distribution (Hardesty and Wilcox, 2015; UNEP, 2016). Even when sampling methods are similar, the comparison through time and between surveys to define status and trends can be compromised by a lack of complementary information on physical factors such as oceanographic conditions during the sampling or the proximity to marine litter sources (Maes and Garnacho, 2013). Since open ocean surveying is resource-intensive, the lack of quantitative and consistent datasets of FML abundance in offshore areas also poses an obstacle to assess the environmental status of the EU marine waters (Galgani et al., 2013b; Kershaw et al., 2013).

FML can be detected and monitored at sea by direct human observation from ships (Sá et al., 2016;Arcangeli et al., 2018;Chambault et al., 2018), net trawls (Viršek et al., 2016;Gewert et al., 2017;Lebreton et al., 2018), multispectral and hyperspectral imaging or video combined with intelligent algorithms (Moller, 2016;Topouzelis et al., 2019;Garcia-Garin et al., 2020) and by GPS tags and transmitters (Novelli et al., 2017;Stanev et al., 2019). Net tows and visual reporting are the most popular sampling methods and they are often considered in oceanographic surveys that involve sampling the sea-surface from a multidisciplinary perspective, thus reducing FML monitoring costs (Galgani et al., 2013b;Miliute-Plepiene et al., 2018).

The Bay of Biscay (hereafter BoB) has been described by global and regional models as an accumulation zone for FML (Lebreton et al., 2012; Van Sebille et al., 2012; Pereiro et al., 2019; Rodríguez-Díaz et al., 2020). Over the past few years, macrolitter (Granado et al., 2019; Ruiz et al., 2020) but also microlitter studies in the water surface and biota (Destang, 2019; Franco et al., 2019; Mendoza et al., 2020; Davila et al., 2021) have been carried out to gain a better understanding of the quantities and behaviour of FML within the area. One of the most important surveys combining neuston and visual observations in the BoB is the BIOMAN multidisciplinary survey. BIOMAN was originally conceived to respond to regulations on fisheries and evaluate fish stocks (Santos et al., 2011) but the annual sampling has progressively expanded to respond to different ecosystem descriptors of the MSFD and the Common Fisheries Policy. Since 2016 the survey has adopted an ecosystem approach including FML monitoring and consequently, an extensive and spatially well covered FML dataset is being built as a proxy of the macro and microlitter abundance and distribution. These measurements are complemented by hydrographic measurements to explore the dependence between the spatio-temporal distribution of FML and the oceanographic parameters. Within this context, the main aim of this study is twofold: (i) to provide the first jointly analysis of macro and microlitter abundance (items/km2 and g/km2) and distribution in the BoB from integrated ecosystem survey; and (ii) to assess the influence of oceanographic conditions on the distribution of macro and microlitter in the BoB.

Data presented in this study were collected between May 2017 and May 2019 (Fig 5.1) on board R/V Ramón Margalef, based on two complementary methodologies: (i) collection of microlitter by neuston net tows and (ii) visual observation of macrolitter items at the sea surface. Microlitter samples were collected using neuston net with a mesh size of 500 µm (2017) and 300 µm (2018 and 2019) and a mouth opening of 100 × 50 cm. The net was deployed at the side of the vessel and positioned away enough from the wake zone to prevent turbulence in microlitter collection. The net towed for 20 min at a towing depth of approximately 35 cm and with a vessel speed of 2 knots. After the tow, the net was rinsed onboard to ensure that all microlitter were washed into the cod-end. Each sample was coded and stored in a zip bag and then frozen at –20 °C. Once on land, the samples were processed at the laboratory. Samples were sonicated when necessary to isolate microlitter from plankton. Microlitter items were extracted from the samples with the aid of a stereoscopic microscope (SMZ-2T from Nikon) and placed into petri-dish. Once extraction finished, the petri-dishes, which were covered to avoid pollution, were introduced in the laboratory oven (ED400 from Binder) at low temperature (30–40 °C) and without ventilation during overnight. Microlitter items were counted and classified according to their size: micro (<5 mm), meso (5 mm - 2.5 cm) and macro (>2.5 cm) litter and type of item: paints, fibers and others. Quantities for shape, size, polymer, and/or color categories were not reported. Blank controls were routinely performed to determine if any contamination occurred at lab. The blanks returned uncontaminated thus no blank correction procedure was applied to microlitter results. Litter densities per water surface area (as items/km2 and g/km2) were calculated by dividing the total number and the dry weight of litter collected in each tow by the area sampled to be in line with the recommendations of Belz et al. (2021).

The corresponding abundances were adjusted following the method proposed by Kukulka et al. (2012). To this end, surface layer particles resulting from the wind-driven mixing were corrected based on the wave height and wind velocity measurements.

Macrolitter observations were performed by one observer during daytime from the highest accessible point of the vessel (7.5 m above the sea surface) following line-transect methodology (Buckland et al., 2001). The observer scanned the water covering a sampling area of 90° centered on the track line (45° to port or starboard). Observation effort was georeferenced every minute with the vessel GPS. Surveyed transects were split into observation periods of identical detection conditions (legs). For each leg, the observer recorded the detection conditions of the sightings and the estimated detection distance and angle between the litter and the track line. Macrolitter items were counted and classified by type of material and type of item according to the categories defined by the technical subgroups of Marine Litter of the MSFD (Galgani et al., 2013b) (Supplementary Table 5.1)

Distance Sampling methodology was applied to estimate floating macrolitter density. Half-normal and hazard rate detection functions were fitted to litter items using Conventional (CDS) and Multiple-Covariate Distance Sampling (MCDS) (Buckland et al., 2001) with the R-package 'distance' (Miller et al., 2019), including the effect of covariates on the detection probability in the case of the MCDS. Best detection functions were selected based on the lowest Akaike Information Criterion (AIC) value as well as by inspection of Q-Q plots and Cramer-von Mises goodness of fit test (García-Barón et al., 2019). The effective strip half-width (ESW) was calculated as the perpendicular distance in which the missing detections at lower distances were equal to the recorded detections at greater distances.

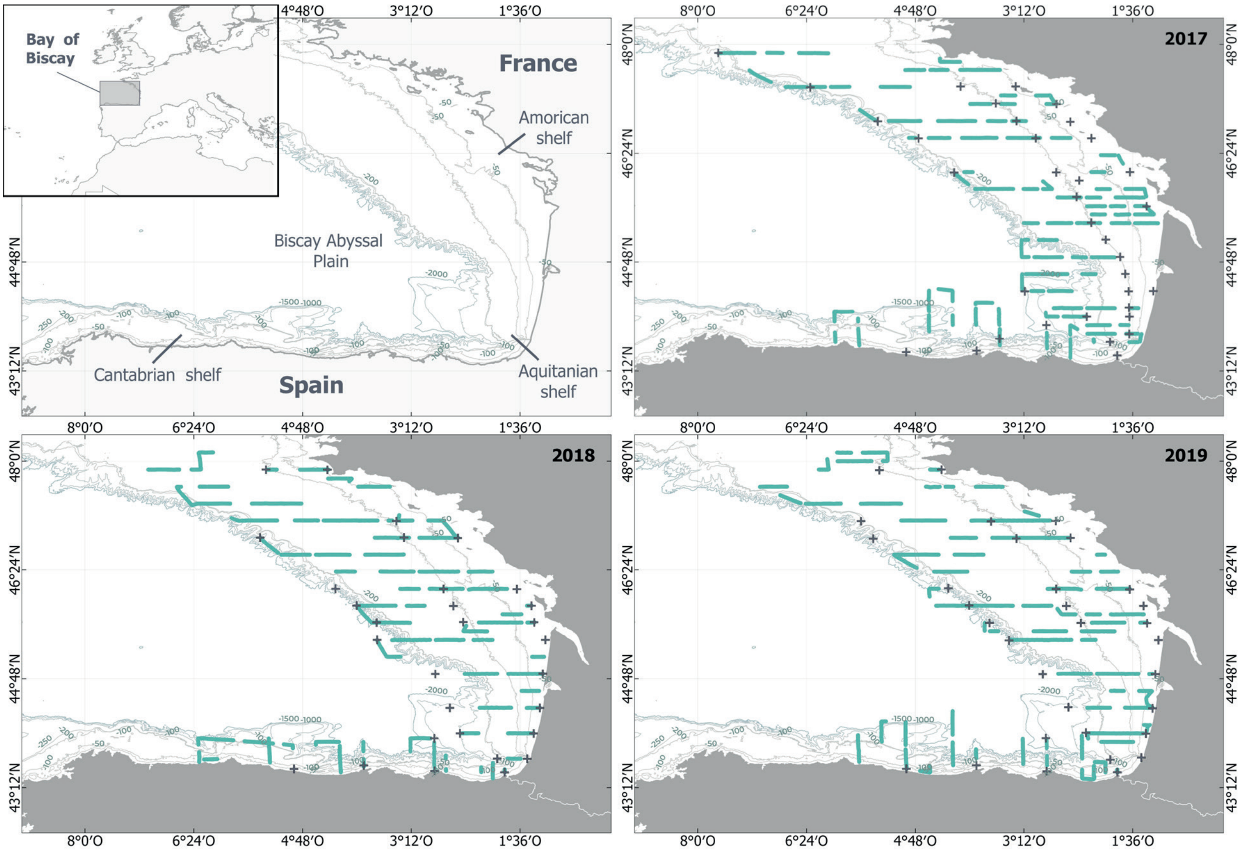


Fig 5.1. Map of the study area, survey effort for visual observations (in coloured lines) and microlitter stations (represented by black crosses) during BIOMAN 2016 - 2019.

ESW was used to estimate the effective sampled area (ESA) as L × 2 × ESW, where L is the length of the leg in km. Macrolitter densities were estimated dividing the number of items observed by the effective sampled area and plotted for the surveyed leg. Macrolitter densities were estimated dividing the number of items observed by the effective sampled area and plotted for the surveyed leg. CTD casts were used to obtain vertical profiles of temperature and salinity at predetermined stations ranging from 100 m depth to a maximum of 5 m depth above the seafloor in shallower areas. Wave height and wind velocities were also measured during the sampling and the bathymetry was obtained from EMODnet Bathymetry portal (Martín Míguez et al., 2019). Annual temperature, salinity and seawater density interpolated maps were obtained from 2017 to 2019 with a 5 m depth resolution (from 10 to 100 m).

An Optimal Statistical Interpolation (OSI) scheme (Gomis et al., 2001) was performed previously to create a regular horizontal grid of 0.15° node distance. Low quality data at near-surface bins prevented the computation of interpolated maps at depth levels over 10 m. Dynamic height field was derived from density, by using a fixed reference level of 100 m. Surface geostrophic velocities (m/s) at 10 m depth were then obtained by the first derivative between adjacent grid nodes of the dynamic height interpolated fields. The Spearman's rank correlation coefficient was also calculated annually between macro and micro litter densities and oceanographic variables to assess the influence of the variability on hydrographic and hydrodynamic conditions in driving the spatial distribution patterns of litter. Densities were compared to temperature, salinity and geostrophic velocity data. The analyses were performed per year and also jointly for the entire study period.

Table 5.1. Summary survey effort, quantities and mean densities of floating macrolitter from vessel-based visual observations for years 2017, 2018 and 2019.

Year	Nº legs	Effort time (h)	Mean observation period per day (h)	Effort distance (km)	Mean distance travelled per day (km)	Nº items	Mean densities (items/km2) ± sd
2017	313	103	5.44	1522	100.103	72	2.52 ± 1.86
2018	308	97	5.09	1849	97.338	97	3.54 ± 2.99
2019	336	94	4.95	1902	96.635	79	3.70 ± 2.34

Table 5.2. Summary survey effort and corrected and non-corrected mean annual densities (items km-2 and g km-2) of floating microlitter for 2017, 2018 and 2019.

			Mean density non corrected		**Mean density corrected**	
Year	Nº samples	Effort Area (km2)	Count (items km-2) ± sd	Weight (g km-2) ± sd	Count (items km-2) ± sd	Weight (g km-2) ± sd
2017	35	118,291	11,212 ± 22,363	2.56 ± 5.80	26,056 ± 43,420	4.24 ± 8.05
2018	30	116,284	201,484 ± 131,460	89.93 ± 237.37	471,250 ± 397,057	190.57 ± 436.15
2019	32	117,111	853,310 ± 1,009,987	47.46 ± 102.89	1,782,454 ± 2,794,465	79.83 ± 134.86

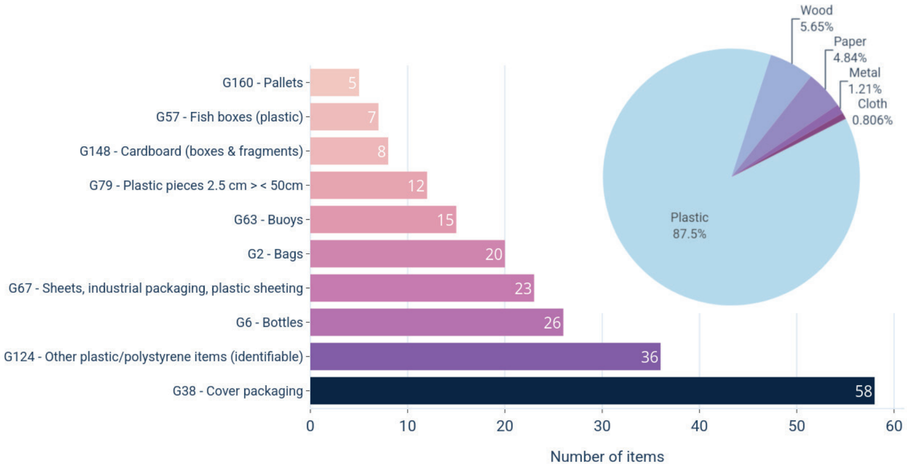


Fig 5.3. Floating macrolitter composition by type of material (right) and top ten items (left) from vessel-based visual observations for years 2017, 2018 and 2019.

A total of 5,587 km distributed in 1,102 legs were surveyed in May during the period 2017-2019 to collect visual data on macrolitter (Table 5.1). A total of 248 items were sighted, mostly plastic (87.5%) (Fig 5.3). "Plastic cover packaging items" (23.39%) and "Other plastic/polystyrene items" (14.52%) were the most abundant items followed by "Bottles" (10.48%), "Sheets, industrial packaging, plastic sheeting" (9.27 %) and "Plastic bags" (8.06%). Approximately 13.31% of the litter observed was attributed to sea-based sources. However, the majority of the litter items could not be directly related to a particular source.

ESW estimated to calculate macrolitter density was 44.802 m. Thus, ESA was calculated for every leg according to the estimated ESW and the reported leg length. Macrolitter density barely varied amongst years (Fig 5.2). The mean of macrolitter density was 3.13 ± 2.46 items/km2 (range 0.34–15.03 items/km2). The highest macrolitter densities were observed in 2018 over the inner area of the BoB, in the transboundary waters between France and Spain - 15.03 items/km2, in 2017 nearby the French slope (between 44°N 46°N) - 13.07 items/km2 and in 2018 in the Armorican shelf at depth level over 100 m - 12.83 items/km2. The lowest macrolitter densities were sighted in 2018 – 0.34 items/km2 and 0.36 items/km2 and in 2019 - 0.42 items/km2 over the French slope in the upper limit of the surveyed area.

A total of 97 microlitter samples were collected for a total distance of 92.8 km surveyed within the study area every May for the period 2017-2019 (Table 5.2). Floating microlitter was encountered in almost all the surveys. Distribution mapping of microlitter corrected densities was performed annually (Figure 5.2). The distribution of microlitter by the continental shelf and the shelf break (locations with depths over >200 m) shows a different trend amongst the years. While in 2017 the highest densities were found on the shelf (Aquitanian shelf nearby Garonne River and in the Armorican shelf), in 2018 and 2019 this area was attributed to slope. Nonetheless, all years agreed in highlighting the deepest regions as the areas with smallest densities.

The temporal evolution of the oceanographic variables (temperature, salinity and geostrophic velocity) showed high interannual variability (Supplementary Fig 5.1). Minimum temperature and salinity values were observed over the French coast and the most intense geostrophic velocities were observed over the shelf concurring with the most intense temperature and salinity gradients. No significant correlation between microlitter density and the oceanographic variables was detected (Supplementary Table 5.4). Neither macro nor microlitter densities were correlated. Bathymetry was the variable that showed the greatest significance for FML spatial distribution in BoB.

The mean corrected density by number of items fells in the same range of the values observed by Öztekİn and Bat (2017) in the Black Sea (656,000 items/km2) and considerably higher than those observed by Gewert et al. (2017) in the Baltic Sea (110,000 items/km2) or by Palatinus et al. (2019) in the Mediterranean Sea (127,135 ± 294,847 items/km2). The different geographical and oceanographical features, techniques for sampling - neuston trawls for the Black Sea and manta trawls for the Baltic and Mediterranean Sea, or the analysis of samples – the non-application of wind corrections – can make the comparison amongst different studies a critical issue. Concerning the quantities and distribution of microlitter in the BoB, several studies provided different estimations (Mendoza et al., 2020). More specifically the ETOILE survey (Davila et al., 2021) and the LIFE LEMA project (Destang, 2019) analyzed microlitter densities in surface waters of the south-eastern BoB (SE BoB hereafter) during 2017 and 2018. ETOILE survey was carried out in summer of 2017 and LIFE LEMA sampling was performed in summer 2017 and autumn 2018. Abundances differed in both studies, being higher in LIFE LEMA (314,574 ± 412,972 items/km2, maximum 2,618,971 items/km2 in 2017 and 1,678,532 ± 4,534,007 items/km2, maximum 26,384,897 items/km2 in 2018) than in ETOILE (4981 ± 4393 items/km2, maximum 16,448 items/km2). Microlitter densities measured in this work were higher than the ones obtained in ETOILE but smaller than those from LIFE LEMA (Basurko et al., 2021, in prep). These results may lead to think that seasonal variability of the oceanographic conditions in the BoB could be one reason for these density differences as Pereiro et al. (2019) reported. However, the high standard deviation values of the annual densities indicate that there is also a spatial variability in the observed distributions, showing big differences also in studies performed in the same season but covering different areas within the BoB. Indeed, LIFE LEMA sampling was done in coastal waters, in contrast to the coastal and offshore ETOILE and BIOMAN surveys. Litter densities are generally higher in coastal areas next to large population and tourist areas. In particular, FML concentrations in the SE BoB are higher compared to other European regions, probably due to the high population density in the surrounding coastal areas or the influence of major rivers discharges (Galgani et al., 2000). Recent modelling studies also suggest that oceanographic conditions and wind drift have a great influence on the transport and accumulation rate of FML where longer residence times and higher FML concentrations are observed in the SE BoB in comparison to the rest of the basin (Pereiro et al., 2019; Ruiz et al., 2022).

Microlitter quantification and classification based on material properties (shape, size, polymer, and/or color categories) is still highly limited at present. The heterogeneity in sample processing methodologies makes comparison between studies quite complex. However, ongoing actions working towards harmonization and standardization procedures of microlitter analysis urge to perform multiple quantification assessments for the study area. Besides, counts by total number and type of item, and more in-depth polymer type analysis can provide valuable and complementary information necessary to identify sources of microlitter. This becomes pivotal to fully understand the current environmental status of the Bay of Biscay and consequently develop preventive and feasible microlitter pollution measures.

Macrolitter densities were considerable higher compared to values reported for the Baltic Sea - <1 item/km2, Rothäusler et al. (2019), within the range for the Mediterranean Sea - 1.9–4.7 items/km2, Arcangeli et al. (2018) and lower when comparing to the Black Sea - 41.5 items/km2, Berov and Klayn (2020) or the Adriatic Sea - 31–114 items/km2 Carlson et al. (2017). However, note that differences in methodologies exist between studies undertaken in these marine regions Macrolitter quantities and distribution results can be compared to the ones of Ruiz et al. (2020), who sampled litter windrows Cózar et al. (2021) in the coastal area of the SE BoB. Ruiz et al. (2020) identified that 96% of the items collected were plastic, being similar to the 87.5% of plastic items sighted in this study. Both results fall within the global reported ranges (UNEP and GRID-Arendal, 2016; Morales-Caselles et al., 2021). In the litter windrows, "plastic pieces 2.5-50 cm" and "string and cords" items were the most abundant categories with 40.46% and 27.09% respectively. All other groups did not even reach the 4%. In contrast with Ruiz et al. (2020), high concentration of fishing material (35%) was sighted being classified according to their origin as sea-based sourced items. The different methodology used (sampling in their case and sighting in this study) could be the reason of the discrepancies in the results, even as observations from vessels are able to cover larger sampling areas, semi-submerged macrolitter (i.e. cords, nets…) is often overlooked Galgani et al. (2011) and smaller items like plastic pieces could be more difficult to see and identify for the observer. Thus, as the case of microlitter, the scale of the study area or the study area itself (which are much smaller and much closer to the coast in the case of Ruiz et al. (2020) could be also the reasons for the differences observed in marine macrolitter abundance.

No significant relationship was found between micro and macrolitter spatial distribution which could be due to different reasons: (i) different sources, (ii) different processes shaping their distributions, and (iii) different sampling strategies. Macrolitter was based on visual observations and microlitter samples were collected with a neuston net, being macrolitter continuously surveyed along the transects and microlitter only sampled in discrete stations, resulting in a different sampling effort. However, a significant correlation between macro and microlitter and bathymetry was observed all the years but 2017.

Larger plastic items are kept in a narrow coastal fringe by winds, which favors their beaching (Rodríguez-Díaz et al., 2020; Morales-Caselles et al., 2021) and after their fragmentation, they could enter again in the BoB as microlitter. In fact, as Mendoza et al. (2020) pointed out, the main source of microlitter in the BoB is more related to the fragmentation of larger plastic items rather than to the direct input of microlitter, which could explain the spatial distribution differences. Besides, this could also explain the pronounced increase of microlitter densities over the years in BoB while macrolitter densities only changed slightly. The oceanography of the BoB presented a marked interannual variability, so did the FML densities. However, no general trends were observed in the correlation between hydrodynamic variables and the distribution of micro and macrolitter. These results suggest that other forcing factors not studied in this work would modulate the spatial distribution of FML. Smaller scale and vertical transport processes could modulate this distribution, as this study was focused exclusively on surface layers and did not consider transformations such as ingestion, biofouling or fragmentation that could suffer FML. The obtained statistical results could also reflect the need of a more intensive sampling and larger time-series dataset.

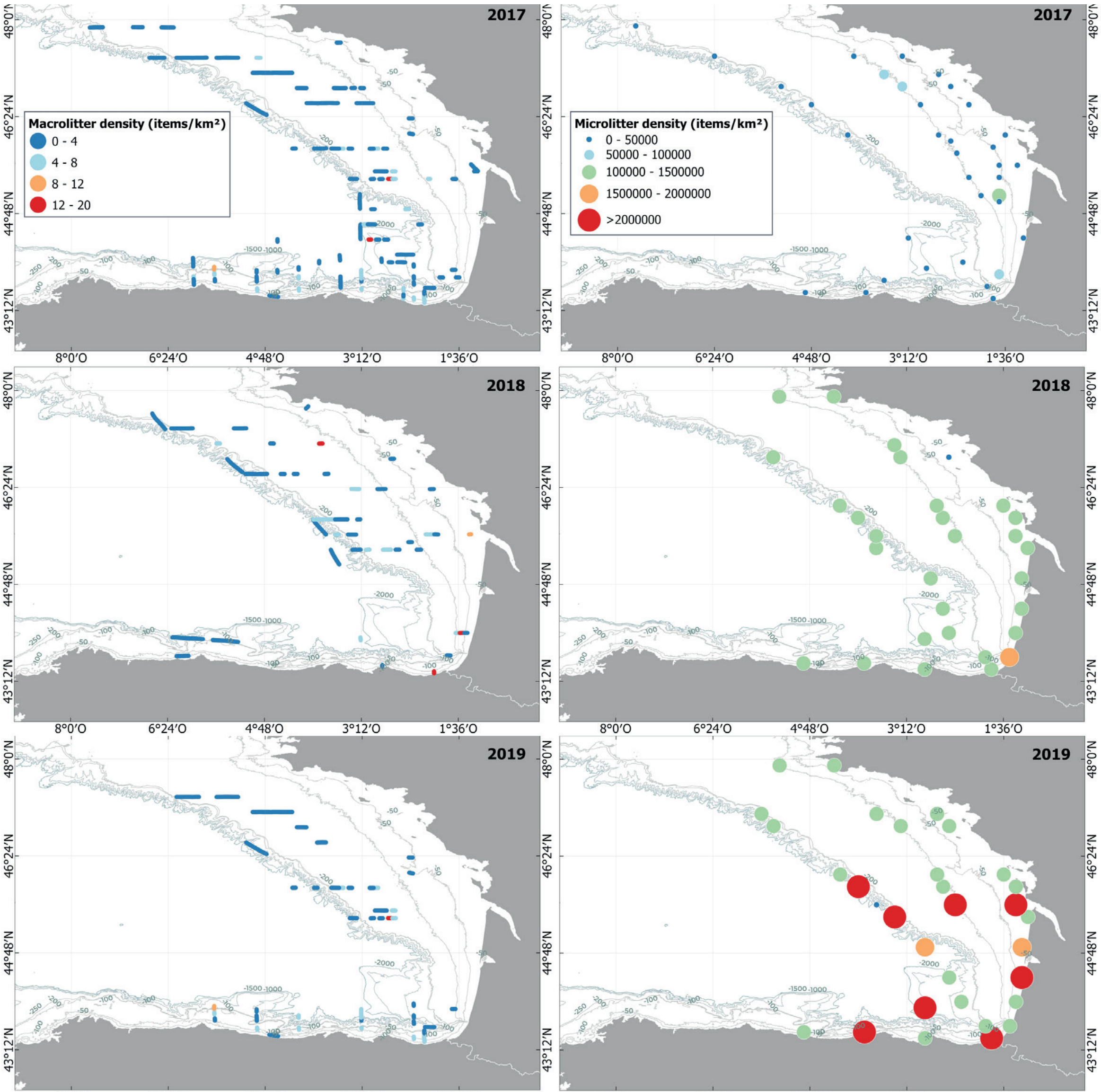


Fig 5.2. Spatial distribution of floating macrolitter (left) and microlitter densities (right) corrected with Kukulka model (Kukulka et al., 2012) for 2017, 2018 and 2019.

Long-term micro and macrolitter dataset and harmonized methods underpinning environmental indicators are crucial to advance measurement of the state of FML in the environment and tackle this issue from local to global scale. In this work, existing FML dataset from BIOMAN multidisciplinary surveys have been explored for the first time to gain knowledge on the micro and macrolitter quantities and distribution under different hydrodynamic conditions, as well as to set the methodological basis that could allow monitoring these quantities in an interannual time scale. Despite the limited and relatively new data collected so far, FML dataset from BIOMAN demonstrate that integrated ecosystem surveys can constitute the starting point for the establishment of a data collection framework to be applied at the regional level in the BoB. This framework could be helpful in future research to study the evolution of FML quantity and distribution (linked for instance to climate change or the establishment of mitigation measures). Moreover, it could be useful to conduct environmental impact assessments, such as those derived from the interaction between different endangered, threatened and protected species with different types of marine litter.

AUTHORS CONTRIBUTION

IR: investigation, data treatment, graphical work, writing up and editing; IB: investigation, data treatment and graphical work; MS: conceptualization, methodology, data management, supervision, review and editing; ML: conceptualization, methodology, intellectual contribution, supervision, review and editing; IG-B: methodology, data treatment, review and editing; CV: data treatment; OCB: intellectual contribution, supervision, review and editing; AU: data base conceptualization; AR: conceptualization, methodology, intellectual contribution, supervision, review and editing.

ACKNOWLEDGEMENTS

We thank to all crew and scientists participating in the BIOMAN surveys on both the R/Vs ‘RamónMargalef’ and ‘Emma Bardán, especially to the observers José Luis Murcia and José Cedeira. This study is a contribution to the IM20MPDH project, funded by the EMFF (European Maritime Fishing Funds) Data collection framework, the “Departamento de Desarrollo Económico y Competitividad” of the Basque Government and the Secretaría General de Pesca of the Spanish Government providing the oceanographic vessels Emma Bardán. I.G-B. was funded by a PhD fellowship from the Spanish Government (BES-2014-070597) and M.L. was funded by a Ramón y Cajal (RYC-2012-09897) contract from the Spanish Government. This is contribution number 1081 of AZTI - Marine Research (BRTA).

References

Arcangeli, A., Campana, I., Angeletti, D., Atzori, F., Azzolin, M., Carosso, L., Di Miccoli, V., Giacoletti, A., Gregorietti, M., Luperini, C., Paraboschi, M., Pellegrino, G., Ramazio, M., Sarà, G., and Crosti, R. (2018). Amount, composition, and spatial distribution of floating macro litter along fixed trans-border transects in the Mediterranean basin. Marine Pollution Bulletin 129, 545-554.

Berov, D., and Klayn, S. (2020). Microplastics and floating litter pollution in Bulgarian Black Sea coastal waters. Marine Pollution Bulletin 156, 111225.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., and Thomas, L. (2001). Introduction to distance sampling: estimating abundance of biological populations.

Carlson, D.F., Suaria, G., Aliani, S., Fredj, E., Fortibuoni, T., Griffa, A., Russo, A., and Melli, V. (2017). Combining Litter Observations with a Regional Ocean Model to Identify Sources and Sinks of Floating Debris in a Semi-enclosed Basin: The Adriatic Sea. Frontiers in Marine Science 4.

Cózar, A., Aliani, S., Basurko, O.C., Arias, M., Isobe, A., Topouzelis, K., Rubio, A., and Morales-Caselles, C. (2021). Marine Litter Windrows: A Strategic Target to Understand and Manage the Ocean Plastic Pollution. Frontiers in Marine Science 8.

Chambault, P., Vandeperre, F., Machete, M., Lagoa, J.C., and Pham, C.K. (2018). Distribution and composition of floating macro litter off the Azores archipelago and Madeira (NE Atlantic) using opportunistic surveys. Marine Environmental Research 141, 225-232.

Davila, X., Rubio, A., Artigas, L.F., Puillat, I., Manso-Narvarte, I., Lazure, P., and Caballero, A. (2021). Coastal submesoscale processes and their effect on phytoplankton distribution in the southeastern Bay of Biscay. Ocean Sci. 17, 849-870.

Destang, T. (2019). “Modelling Microplastics in the SE Bay of Biscay. MsC Thesis for the Marine Environment and Resources Erasmus Mundus Master Degree”. EHU, Plentzia).

Franco, J., Fort, J., García-Barón, I., Loubat, P., Louzao, M., Del Puerto, O., and Zorita, I. (2019). Incidence of plastic ingestion in seabirds from the Bay of Biscay (southwestern Europe). Marine Pollution Bulletin 146, 387-392.

Galgani, F., Hanke, G., and Maes, T. (2015). “Global Distribution, Composition and Abundance of Marine Litter,” in Marine Anthropogenic Litter, eds. M. Bergmann, L. Gutow & M. Klages. (Cham: Springer International Publishing), 29-56.

Galgani, F., Hanke, G., Werner, S., and De Vrees, L. (2013a). Marine litter within the European Marine Strategy Framework Directive. ICES Journal of Marine Science 70, 1055-1064.

Galgani, F., Hanke, G., Werner, S., Oosterbaan, L., Nilsson, P., Fleet, D., Kinsey, S., Thompson, R., Van Franeker, J., and Vlachogianni, T. (2013b). Monitoring guidance for marine litter in European seas. JRC Scientific and Policy Reports, EUR 26113.

Galgani, F., Hanke, H., and Werner, S. (2011). Marine litter technical recommendations for the implementation of MSFD requirements, report of the MSFD GES Technical Subgroup on Marine Litter, EUR 25009 EN 2011.

García-Barón, I., Authier, M., Caballero, A., Vázquez, J.A., Santos, M.B., Murcia, J.L., and Louzao, M. (2019). Modelling the spatial abundance of a migratory predator: A call for transboundary marine protected areas. Diversity and Distributions 25, 346-360.

Garcia-Garin, O., Aguilar, A., Borrell, A., Gozalbes, P., Lobo, A., Penadés-Suay, J., Raga, J.A., Revuelta, O., Serrano, M., and Vighi, M. (2020). Who’s better at spotting? A comparison between aerial photography and observer-based methods to monitor floating marine litter and marine mega-fauna. Environmental Pollution 258, 113680.

Gewert, B., Ogonowski, M., Barth, A., and Macleod, M. (2017). Abundance and composition of near surface microplastics and plastic debris in the Stockholm Archipelago, Baltic Sea. Marine Pollution Bulletin 120, 292-302.

Gomis, D., Ruiz, S., and Pedder, M.A. (2001). Diagnostic analysis of the 3D ageostrophic circulation from a multivariate spatial interpolation of CTD and ADCP data. Deep Sea Research Part I: Oceanographic Research Papers 48, 269-295.

Granado, I., Basurko, O.C., Rubio, A., Ferrer, L., Hernández-González, J., Epelde, I., and Fernandes, J.A. (2019). Beach litter forecasting on the south-eastern coast of the Bay of Biscay: A bayesian networks approach. Continental Shelf Research 180, 14-23.

Hardesty, B.D., and Wilcox, C. (2015). “Modelling and monitoring of marine litter”. (CSIRO Hobart).

Kershaw, P., Hartley, B., Garnacho, E., and Thompson, R. (2013). Understanding of distribution, quantities, and types of marine litter.

Kershaw, P., Turra, A., and Galgani, F. (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. GESAMP reports and studies.

Klein, N., Arroyo Schnell, A., Giron, E., and Sousa, J. (2017). National marine plastic litter policies in EU Member States: an overview.

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. Geophysical Research Letters 39.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., and Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports 8, 4666.

Lebreton, L.C.M., Greer, S.D., and Borrero, J.C. (2012). Numerical modelling of floating debris in the world’s oceans. Marine Pollution Bulletin 64, 653-661.

Maes, T., and Garnacho, E. (2013). Summary of methods to monitor and assess marine litter.

Martín Míguez, B., Novellino, A., Vinci, M., Claus, S., Calewaert, J.-B., Vallius, H., Schmitt, T., Pititto, A., Giorgetti, A., Askew, N., Iona, S., Schaap, D., Pinardi, N., Harpham, Q., Kater, B.J., Populus, J., She, J., Palazov, A.V., Mcmeel, O., Oset, P., Lear, D., Manzella, G.M.R., Gorringe, P., Simoncelli, S., Larkin, K., Holdsworth, N., Arvanitidis, C.D., Molina Jack, M.E., Chaves Montero, M.D.M., Herman, P.M.J., and Hernandez, F. (2019). The European Marine Observation and Data Network (EMODnet): Visions and Roles of the Gateway to Marine Data in Europe. Frontiers in Marine Science 6.

Mendoza, A., Osa, J.L., Basurko, O.C., Rubio, A., Santos, M., Gago, J., Galgani, F., and Peña-Rodriguez, C. (2020). Microplastics in the Bay of Biscay: An overview. Marine Pollution Bulletin 153, 110996.

Miliute-Plepiene, J., Fråne, A., Haikonen, K., and Youhanan, L. (2018). Overview of available methods to monitor marine plastic litter Incl. method for riverine litter monitoring developed within BLASTIC.

Miller, D.L., Rexstad, E., Thomas, L., Marshall, L., and Laake, J.L. (2019). Distance Sampling in R. 2019 89, 28.

Moller, D. (Year). “SAR and IfSAR observational concepts for marine debris mapping and oceanic monitoring”, in: Presentation at Workshop on Mission Concepts for Marine Debris Sensing).

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S., Basurko, O.C., Mallos, N., Lebreton, L., Echevarría, F., Van Emmerik, T., Duarte, C.M., Gálvez, J.A., Van Sebille, E., Galgani, F., García, C.M., Ross, P.S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., and Cózar, A. (2021). An inshore–offshore sorting system revealed from global classification of ocean litter. Nature Sustainability 4, 484-493.

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.

Pereiro, D., Souto, C., and Gago, J. (2019). Dynamics of floating marine debris in the northern Iberian waters: A model approach. Journal of Sea Research 144, 57-66.

Rodríguez-Díaz, L., Gómez-Gesteira, J.L., Costoya, X.,Gómez-Gesteira, M., and Gago, J. (2020). The Bay of Biscay as a trapping zone for exogenous plastics of different sizes. Journal of Sea Research 163, 101929.

Rothäusler, E., Jormalainen, V., Gutow, L., and Thiel, M. (2019). Low abundance of floating marine debris in the northern Baltic Sea. Marine Pollution Bulletin 149.

Ruiz, I., Abascal, A.J., Basurko, O.C., and Rubio, A. (2022). Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas. Environmental Pollution 292, 118216.

Ruiz, I., Basurko, O.C., Rubio, A., Delpey, M., Granado, I., Declerck, A., Mader, J., and Cózar, A. (2020). Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter. Frontiers in Marine Science 7.

Ryan, P.G. (2015). “A Brief History of Marine Litter Research,” in Marine Anthropogenic Litter, eds. M. Bergmann, L. Gutow & M. Klages. (Cham: Springer International Publishing), 1-25.

Sá, S., Santos, J.M., Araújo, H., Ferreira, M., Duro, V., Alves, F., Panta-Ferreira, B., Nicolau, L., Eira, C., and Vingada, J. (2016). Spatial distribution of floating marine debris in offshore continental Portuguese waters. Marine Pollution Bulletin 104.

Santos, M., Uriarte, A., and Ibaibarriaga, L. (2011). Spawning Stock Biomass estimates of the Bay of Biscay anchovy (Engraulis encrasicolus L.) in 2010 applying the Daily Egg Production Method. RIM 18, 76-91.

Smail, E., Campbell, J., Takaki, D., Plag, H.-P., Garello, R., Djavidnia, S., Moutinho, J., El Serafy, G., Giorgetti, A., and Vinci, M. (2020). A Global Platform for Monitoring Marine Litter and Informing Action.

Stanev, E., Badewien, T., Freund, H., Grayek, S., Hahner, F., Meyerjürgens, J., Ricker, M., Schöneich-Argent, R., Wolff, J.-O., and Zielinski, O. (2019). Extreme westward surface drift in the North Sea: Public reports of stranded drifters and Lagrangian tracking. Continental Shelf Research 177, 24-32.

Topouzelis, K., Papakonstantinou, A., and Garaba, S.P. (2019). Detection of floating plastics from satellite and unmanned aerial systems (Plastic Litter Project 2018). International Journal of Applied Earth Observation and Geoinformation 79, 175-183.

Unep (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change.

Unep and Grid-Arendal (2016). “Marine Litter Vital Graphics., United Nations Environment Programme and GRID-Arendal”. (Nairobi and Arendal).

Van Sebille, E., England, M.H., and Froyland, G. (2012). Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environmental Research Letters 7, 044040.

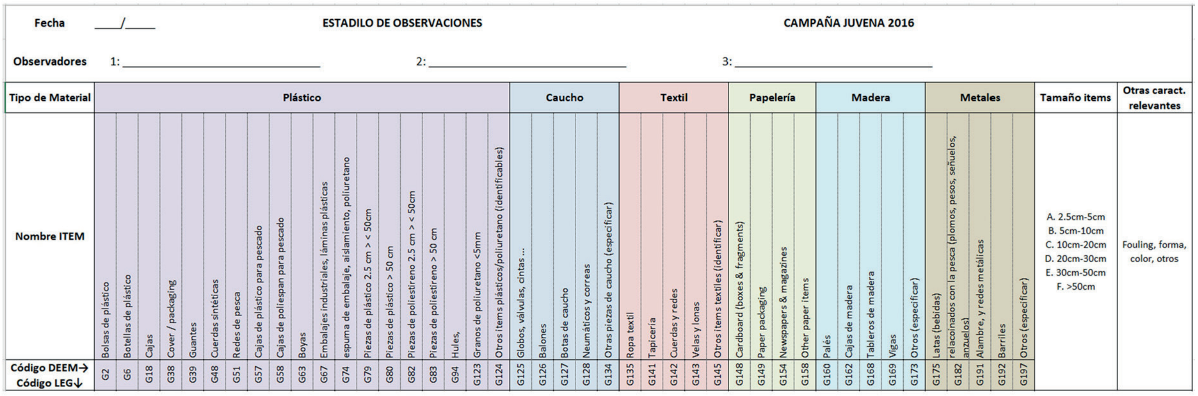
Viršek, M., Palatinus, A., Koren, Š., Peterlin, M., Horvat, P., and Kržan, A. (2016). Protocol for Microplastics Sampling on the Sea Surface and Sample Analysis. Journal of Visualized Experiments 2016.

Walker, T.R. (2021). (Micro)plastics and the UN Sustainable Development Goals. Current Opinion in Green and Sustainable Chemistry 30, 100497.

Supplementary material

Supplementary Table 5.1

Supplementary Table 5.1. Data sheet for recording floating macrolitter items by visual observations.



Fecha ____/____ **ESTADILO DE OBSERVACIONES** **CAMPAÑA JUVENA 2016**

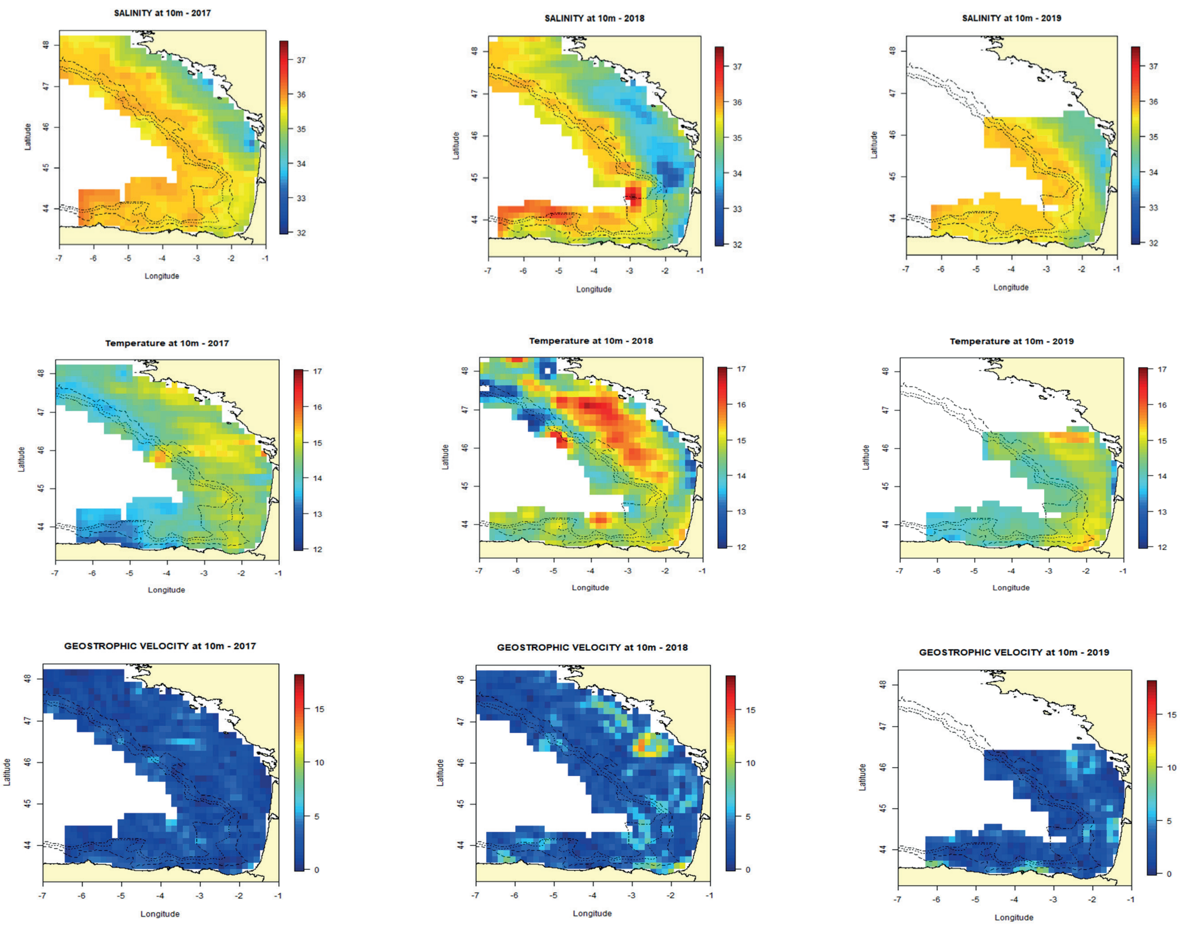
Observadores 1: ____________________ 2: ____________________ 3: ____________________

Tipo de Material	**Plástico**																			
Nombre ITEM	Bolsas de plástico	Botellas de plástico	Cajas	Cover / packaging	Guantes	Cuerdas sintéticas	Redes de pesca	Cajas de plástico para pescado	Cajas de poliespan para pescado	Boyas	Embalajes industriales, láminas plásticas	espuma de embalaje, aislamiento, poliuretano	Piezas de plástico 2.5 cm > < 50cm	Piezas de plástico > 50 cm	Piezas de poliestireno 2.5 cm > < 50cm	Piezas de poliestireno > 50 cm	Hules,	Granos de poliuretano <5mm	Otros items plásticos/poliuretano (identificables)
Código DEEM→ Código LEG↓	G2	G6	G18	G38	G39	G48	G51	G57	G58	G63	G67	G74	G79	G80	G82	G83	G94	G123	G124

Tipo de Material	**Caucho**					**Textil**					**Papelería**			
Nombre ITEM	Globos, válvulas, cintas ...	Balones	Botas de caucho	Neumáticos y correas	Otras piezas de caucho (especificar)	Ropa textil	Tapicería	Cuerdas y redes	Velas y lonas	Otros items textiles (identificar)	Cardboard (boxes & fragments)	Paper packaging	Newspapers & magazines	Other paper items
Código DEEM→ Código LEG↓	G125	G126	G127	G128	G134	G135	G141	G142	G143	G145	G148	G149	G154	G158

Tipo de Material	**Madera**					**Metales**					**Tamaño items**	**Otras caract. relevantes**
Nombre ITEM	Palés	Cajas de madera	Tableros de madera	Vigas	Otros (especificar)	Latas (bebidas)	relacoinados con la pesca (plomos, pesos, señuelos, anzuelos)	Alambre, y redes metálicas	Barriles	Otros (especificar)	A. 2.5cm-5cm B. 5cm-10cm C. 10cm-20cm D. 20cm-30cm E. 30cm-50cm F. >50cm	Fouling, forma, color, otros
Código DEEM→ Código LEG↓	G160	G162	G168	G169	G173	G175	G182	G191	G192	G197		

Supplementary Figure 5.1



Supplementary Fig 5.1. Interpolated salinity, temperature,and geostrophic velocities at 10m depth for the survey period 2017 to 2019.

Supplementary Table 5.2

Supplementary Table 5.2. Abundances of identified macrolitter classified according to the European Master list suggested by the MSFD Technical Group on Marine Litter (MSFD TG ML) and its possible sources.

Litter type	Code	Item	Abundance	%	Source
Plastic	G38	Plastic cover packaging	58	23.39	Multiple
Plastic	G124	Other hard plastic or foamed polystyrene items (identifiable)	36	14.52	Multiple
Plastic	G6	Plastic bottles & containers other than food or personal hygiene and care related	26	10.48	Multiple
Plastic	G67	Plastic sheets, industrial packaging, sheeting	23	9.27	Multiple
Plastic	G2	Plastic bags	20	8.06	Multiple
Plastic	G63	Plastic floats/buoys other source than fishing or not known	15	6.05	Sea-based
Plastic	G79	Fragments of non-foamed plastic 2.5cm ≥ ≤ 50cm	12	4.84	Sea-based
Paper	G148	Cardboard boxes	8	3.23	Sea-based
Plastic	G57	Fish boxes - hard plastic	7	2.82	Sea-based
Wood	G160	Wooden pallets	5	2.02	Sea-based
Wood	G168	Wood boards	5	2.02	Multiple
Plastic	G48	Synthetic rope	5	2.02	Multiple
Plastic	G82	Fragments of foamed polystyrene 2.5 cm ≥ ≤ 50 cm	5	2.02	Non sourced
Plastic	G18	Plastic crates, boxes, baskets	4	1.61	Non sourced
Paper	G150	Paper cartons/Tetrapak milk	3	1.21	Non sourced
Plastic	G58	Fish boxes - foamed polystyrene	3	1.21	Multiple
Cloth/textile	G142	Rope, string and nets	2	0.81	Sea-based
Wood	G162	Wooden crates, boxes, baskets for packaging	2	0.81	Multiple
Metal	G197	Other metal objects	2	0.81	Multiple
Paper	G149	Paper packaging	1	0.40	Multiple
Wood	G169	Beams / Dunnage	1	0.40	Sea-based
Wood	G173	Other processed wood	1	0.40	Sea-based
Metal	G175	Metal drinks cans	1	0.40	Multiple
Plastic	G39	Plastic gloves	1	0.40	Multiple
Plastic	G51	Fishing net	1	0.40	Multiple
Plastic	G80	Fragments of non-foamed plastic > 50cm	1	0.40	Multiple
TOTAL			**248**	**100**	

Supplementary Table 5.3

Supplementary Table 5.3. Number of litter items collected using a 300 µm and 500µm neuston net in the Bay of Biscay during BIOMAN surveys (2017-2019). Microlitter items (<5mm) were classified into three categories (paints, fibers, and others) according to the type of item.

Year		2017	2018	2019
Size of iitem	<5mm	496	4,814	16,360
	>5mm	182	215	244

Supplementary Table 5.4

Supplementary Table 5.4. Annual Spearman's rank correlation values. In red values that even they are numerically significant can't be considered because of the low quantity of data used to obtain them, as studying features did not match enough times spatially. In bold font significant values.

2017					
		Microlitter density	Macrolitter density	Wind driven litter	Current driven litter
Temperature	R	-0.26	0.067	-0.081	0.2
	p	0.15	0.38	0.68	0.32
Salinity	R	0.1	-0.067	0.033	0.23
	p	0.58	0.38	0.87	0.25
Geostrophic velocity	R	0.014	-0.064	0.05	0.15
	p	0.94	0.4	0.8	0.45
Bathymetry	R	0.13	0.16	-0.023	-0.26
	p	0.52	0.032	0.91	0.15
Microplastic density	R	-	-0.27	-	0.5
	p	-	0.24	-	1
2018					
		Microlitter density	Macrolitter density	Wind driven litter	Current driven litter
Temperature	R	-0.16	-0.039	0.17	0.06
	p	0.4	0.6	0.39	0.74
Salinity	R	0.12	-0.1	-0.042	0.088
	p	0.53	0.17	0.83	0.63
Geostrophic velocity	R	0.57	0.1	0.11	-0.077
	p	0.002	0.16	0.58	0.67
Bathymetry	R	0.16	0.1	-0.023	0.24
	p	0.38	0.18	0.91	0.24
Microplastic density	R	-	-0.25	1	-
	p	-	0.3	0.33	-
2019					
		Microlitter density	Macrolitter density	Wind driven litter	Current driven litter
Temperature	R	0.15	0.11	0.029	0.024
	p	0.43	0.16	0.9	0.91
Salinity	R	0.0086	0.023	0.12	0.095
	p	0.96	0.76	0.61	0.64
Geostrophic velocity	R	0.4	0.05	0.026	0.19
	p	0.29	0.51	0.92	0.36
Bathymetry	R	0.38	0.035	-0.33	-0.22
	p	0.084	0.67	0.2	0.32
Microplastic density	R	-	-0.11	1	0.5
	p	-	0.65	0.33	1

CHAPTER 2

Publication data

Type	Research Paper
Title	The coastal waters of the south-east Bay of Biscay a dead-end for Neustonic plastics
Authors	Oihane C. Basurko1*, Irene Ruiz1, Anna Rubio1, Beatriz Beldarrain1, Deniz Kukul1, Andrés Cózar2, Mateo Galli3, Théo Destang1 and Joana Larreta1
Affiliation	1AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Pasaia, Spain 2Departamento de Biología, University of Cadiz and European University of the Seas (SEA-EU), Instituto Universitario de Investigación Marina (INMAR), Puerto Real, Spain 3Department of Physical, Earth and Environmental Sciences, University of Siena, Via Mattioli 4, 53100 Siena, Italy
Journal	Marine Pollution Bulletin
Year	2022
Volume	-
Stage of publication	Revised and resubmitted

HIGHLIGHTS

01. The coastal south-east of Bay of Biscay is a convergence area for plastics
02. The plastic abundances in the studied area were generally medium-high
03. Abundances in French waters were substantially higher compared with Spanish waters
04. Plastic fragments and transparent microplastics were the most abundant plastic items
05. A strong positive correlation was found between micro and mesoplastic abundances

ABSTRACT

Numerical models point to the south-eastern Bay of Biscay as a convergence area for floating particles, including plastics. However, the few studies on plastic abundance in the area have mainly focused on open waters and yet information on the coastal area is limited. To fill this gap, neustonic samples were taken along the coastal waters of the south-eastern Bay of Biscay (2017-2020) to define the spatial distribution of plastic abundances and composition. Results show an average plastics abundance of 739,395 ± 2,625,271 items/km2 (998 ± 4,338 g/km2). French waters were mostly affected (with 5 times higher plastic abundances than Spanish coasts). Microplastics represented 93% of the total abundance of plastic items (28% in weight), mesoplastics 7% (26%) and macroplastics 1% (46%). This study demonstrates that this area is a hotspot for plastic with levels in coastal waters similar to those in the Mediterranean Sea or other litter aggregation areas.

KEY WORDS

Bay of Biscay; coastal waters; neuston; floating litter; microplastics; marine pollution

INTRODUCTION

Marine litter and plastic pollution have been tagged as a new threat to the oceans. This is supported by the European Marine Strategy Framework Directive, which considers marine litter as one of the Descriptors, i.e., Descriptor 10, to monitor the good environmental status of European seas and oceans. Some authors have argued, that it is not by far one of the most urgent matters, pointing instead to climate change, habitats and biodiversity loss, overfishing, interactions of different pollutants (especially those contaminants of emerging concern such as pharmaceuticals and pesticides), and cumulative impacts of different human pressures (Borja and Elliott, 2019; Tiller et al., 2019). Nonetheless other authors state that they influence all of the above due to their capacity to alter the carbon cycle (Shen et al., 2020) or the transport capacity that marine litter provides to both pollutants and different species (Capolupo et al., 2020; Kesy et al., 2019; Kooi et al., 2017). Regardless, the plastic phenomenon has boomed in a fast-dominated media society, which has rocketed the calls for actions not only to visualize this problem (everybody has seen and/or suffer it) but also to find preventive and mitigating solutions by engaging society, scientific community, and industry together. It is unquestionable that marine litter has become a pressing issue to the public, thereby reaching the top of the agenda for policy makers and governments at all levels (Maes et al., 2019).

The marine litter costs tourism and recreation sector up to €630 million per year, €62 million for fisheries sector, equivalent to a reduction of nearly 1% of the total revenue generated by the EU fleet in 2010 (Van Acoleyen et al., 2013). As an answer to this and other pressing issues, different directives such as the Single-Use Plastic (Directive (EU) 2019/904) and the Port Reception Facilities (Directive (EU) 2019/883), or the Extended Producer Responsibility strategy have been promoted at European level. At local level, several authorities have shown interest in adopting preventive and mitigation solutions, but they lack the understanding on the origin and source of the marine litter that ends washed up in their coastlines, who produces them, and how do they get accumulated or dispersed (Ruiz et al., 2020). One of the examples is the south-east of the Bay of Biscay (SE BoB), which has been highlighted by recent studies based on Lagrangian computations from numerical models and observations as a cul de sac for floating plastic (Declerck et al., 2019; Lebreton et al., 2012; Pereiro et al., 2019; Ruiz et al., 2022a; van Sebille et al., 2012). Some local authorities of this region, i.e., in Gipuzkoa (Spain) the Provincial Council of Gipuzkoa, and in the Pyrénées-Atlantiques (France) the Communauté d'Agglomération Pays Basque and the Ville de Biarritz, have shown interest in providing solutions, but they lacked the knowledge to face this problem and implement valid solutions (pers. comm. as part of LIFE LEMA project).

Despite the ubiquitous presence of floating plastics, there are relatively few reports of joint quantification of micro-, meso- and macro-plastics for the Bay of Biscay (BoB). The first observations performed during micro and macrolitter monitoring actions revealed that micro (756,865 items/km2) and macrolitter abundances (3.13 items/km2) fell in the same range of the values observed in other European regions (Ruiz et al., 2022b). The BoB presents a medium level of microplastic pollution (Mendoza et al., 2020), and modelling studies have recently revealed that microplastics in the BoB tend to be freely scattered oceanward while larger items tend to stay close to shore. Particularly the longest residence times and abundances for the BoB are observed in the SE region of the BoB both for sea-based related floating macro and microplastic (Pereiro et al., 2019; Rodríguez-Díaz et al., 2020; Ruiz et al., 2022a). The coastal waters of the SE BoB also present particular structures at the submesoscale domain (<10 km horizontally), called marine litter windrows, that tend to aggregate floating macrolitter, seafoam, seaweeds (Cózar et al., 2021; Ruiz et al., 2020). Such is the abundance of marine litter windrows in the BoB that local authorities are engaged in active fishing for litter initiatives that aim at retrieve the floating marine litter from the sea-surface of coastal waters along these convergence lines (Andrés et al., 2021).

This contribution, jointly with the work presented in Ruiz et al. (2022a; 2020; 2022b) for micro and macro litter monitoring provide new insights on the background knowledge on marine litter in the BoB and particularly the coastal areas of the SE BoB; information that can assist the local authorities in being more prepared to address plastic pollution in the coastlines they manage. The questions to be answered by the present contribution are how much plastic is in the coastal waters of Gipuzkoa and Pyrénées-Atlantiques (SE BoB), where do plastics accumulate, and when. It also aims to provide a first description on the temporal and spatial differences on the plastic abundances in the study areas, and exploring the possible correlations between plastic abundances and distance to the coastline and depth, and between plastic particles of different size.

This contribution is part of LIFE LEMA project (https://www.lifelema.eu/en/), which was devoted to developing smart tools to monitor, forecast and collect floating marine litter from coastal waters of the SE BoB.

MATERIAL AND METHODS

The study area

The SE BoB (Fig 5.4) is the section of the BoB (a semi-enclosed gulf located in the north-east of the Atlantic Ocean) that encompasses the area between the south-western coast of France and the north-eastern coast of Spain. The continental shelf along the northern Iberian Peninsula is narrow (30 to 40 km width on average) (Solabarrieta et al., 2014), while the shelf increases in width progressively with latitude along the French coast (known as the Armorican and the Aquitanian shelves) (EMODnet, 2019). The coastline along the northern Iberian Peninsula is also steep, with a pronounced continental slope (10 to 12%) and numerous canyons (Borja et al., 2019). It includes a multitude of cliffs between beaches and small bays, while the French coast (from the south to the Loire River mouth) is straight, flat and sandy (OSPAR Commission, 2000). River basins in the peninsula are small, with short rivers that pass through highly industrialised areas, however, in the south-western coast of France are bigger and longer. Water mass balance in this region is mainly influenced by rivers outflow, being the Adour (France) the most important river in the SE BoB. With mean annual discharge flows of 300 m3/s (Morichon et al., 2008), the Adour presents peak flows exceeding 1000 m3/s in spring (Laiz et al., 2014), and runoff under 500 m3/s in summer (Declerck et al., 2019).

The population density is 18 million inhabitants (299.6 inhabitants per km2) (Borja et al., 2019). The main human activities in this maritime region are fishing, maritime transport, and tourism (OSPAR Commission, 2017).The water circulation in the SE BoB is complex and modelled by diverse factors. In winter, the circulation is mainly governed by the Iberian Poleward Current (IPC). The IPC is a seasonal slope current flowing eastwards over the slope of the Spanish coast and northwards over the slope of the French coast (Solabarrieta et al., 2014), which origin lays on the thermohaline circulation (Huthnance, 1986) and it is seasonal (Solabarrieta et al., 2014). In summer, a completely different tendency is observed. The water circulation over the slope is reversed and has intensities three times weaker than those observed in winter, with predominant (westerly) currents over the Spanish slope (Charria et al., 2013; Solabarrieta et al., 2014). During the transition periods (spring, early autumn) no clear pattern is observed, with weak and high variable currents (Charria et al., 2013; Solabarrieta et al., 2014). On the shelf, riverine input, wind intensity, tides, waves and local winds introduce variability in the surface circulation (Charria et al., 2013). The seasonal variability of the main circulation patterns and those resulting from forcings acting locally determine the retention patterns in the area. Findings show a significant spatial and temporal variability on the residence time values, characterized by a strong seasonality with higher retention conditions observed in spring and summer (Declerck et al., 2019; Rubio et al., 2020). In this area, in autumn both the wind and slope current regime favor the rapid evacuation of the particles towards the north, although interannual variability is also observed (Declerck et al., 2019; Rubio et al., 2020).

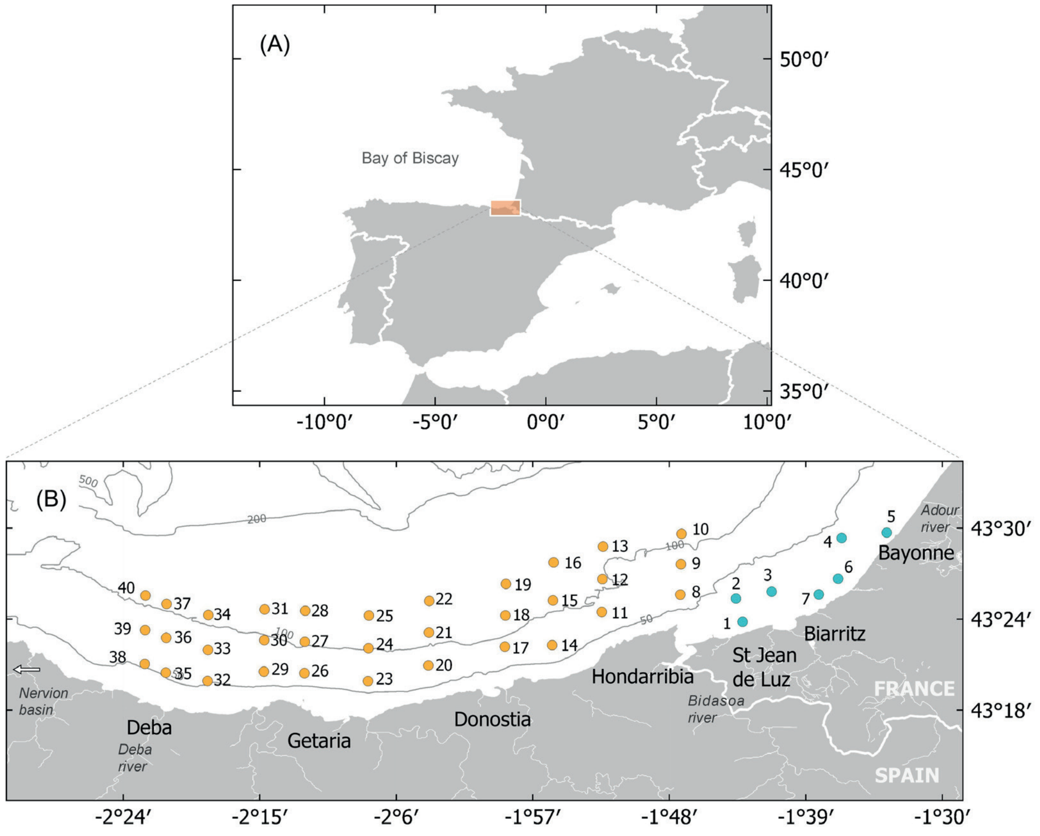


Fig 5.4. Study site located in the SE Bay of Biscay (A), with the Neustonic sampling sites positions (B). The blue points are related to the sampling sites (1-7) of the Pyrénées-Atlantiques coast (France) and the yellow points to the sampling sites (8-40) of Gipuzkoa coast (Spain).

Sampling effort and laboratory work

A total of 190 samples (40 sampling stations) were collected during four sets of cruises onboard Miren Argia F/V (in 2017) and Itsas Belhara F/V (in 2018-2020), covering an area of 85 km (870 km2). Sampling stations were strategically located at 2, 4, and 6 nautical miles from the coast, and in front of / or in between river-mouths (the later if the distance between rivers was larger than average). At each station, one neustonic sample was taken at each sampling month. All samplings were undertaken in areas free of Marine litter Windrow structures. In 2017, due to the availability of the vessels, the sampling focused on the Spanish coastline waters during autumn (Fig 5.4, yellow circles), and samples were taken once per months during September, October, and November 2017, totaling 95 samples (in October only 27 stations could be sampled). Following the same protocol, in the period 2018-2020, the neustonic samples were collected during spring and summer along the French coastline (Fig 5.4, blue circles). The sampling effort (96 samples) focused on the spring and summer months (May to September), and it consisted in the sampling of 7 stations. The sampling effort is summarised in Supplementary table 5.5.

All samples were collected during daylight using a neuston net (100 cm x 50 cm, 500 μm mesh size), towed superficially (approximately the first 35cm of the sea-surface were sampled), and equipped with a mechanical flowmeter to measure the volume of filtered seawater. The net was towed at a speed range of 2-3 knots for 15-20 minutes. After the tow, the net was rinsed onboard with prefiltered seawater to accumulate the entire sample in the cod-end, and then passed to a 335 μm sieve to ensure the retention of the microplastic fraction (>500 μm). Each sample was transferred to a coded plastic bag, which was stored and frozen at -18 degrees Celsius until analysis.

In the laboratory, after being defrosted, the samples were rinsed with tap water and distilled water using a 335 μm sieve. Subsequently, the microplastic items were extracted manually from the samples with the aid of a stereoscopic microscope (SMZ-2T from Nikon). For those samples containing a significant amount of organic matter (plankton and microalgae), a pre-treatment was applied to reduce the organic load of the samples, which consisted of a peroxide oxidation (30% hydrogen peroxide) in the presence of a Fe(II) catalyst (0.05 M) (following Masura et al. (2015)). Afterwards, the mixture was subjected to density separation in NaCl to isolate the plastic items through flotation. When the sample was complex to work under the stereoscopic microscope due to it was too time and effort-consuming, NaOH 6 mol l-1 was added and digested with a Branson UltrasonicsTM Sonifier S-250A (200-Watt, 60 Hertz) set at 25% output control for 0.7 second duration of pulsation. Depending on the quantity and type of organic matter (algae being harder to dissolve than plankton), the sonication varied from 1 to 5 hours. To avoid an excess sample temperature rising, the solution was kept in a cold-water bath for the duration of the process. Afterwards the sample was rinsed with distilled water with 335 μm sieve.

The plastic particles of each sample were extracted under a stereoscopic microscope, classified, and stored according to their size in 3 petri dishes: micro (< 5 mm), meso (5 mm - 2.5 cm) and macro (> 2.5 cm) plastics. The extraction, the size measurement and storage in petri dishes were done manually. The petri dishes were left to be dried for one day, covered with the petri cup, at ambient temperature before being weighted. Blank controls were routinely performed to determine if any contamination occurred at the lab. The blanks returned uncontaminated thus no blank correction procedure was applied to microlitter results. The number of items was also noted by each of the size class. Plastic abundance and mass concentration per water surface area (as items/km2 , items/m3, g/km2, and g/m3) for plastic items in general, and by micro, meso and microplastic categories were calculated by dividing the total number or dry weight of plastics collected in each tow by the estimated area sampled as the product of the trawling distance (derived from the starting and ending coordinates registered with a GPS) and the width of the net opening, and water volume filtered.

Vertical mixing derived from the wind on the sea surface shapes the distribution of plastic in the sea-surface. To represent this phenomenon, some authors adjust the abundances by a method proposed by Kukulka et al., (2012). Despite this, all numerical data present in this contribution refer to data without correction. Only the abundances represented in distribution maps (Fig. 5.5-5.6) were adjusted following Kukulka et al. (2012). In those cases only, and for tows that presented an average friction velocity in water (U*) > 0.6 cm/s (100% of the tows), their corresponding abundances, in terms of item/km2, were adjusted following Kukulka. For the Spanish coastal data, the wave data were extrapolated from the records of the closest buoy, the Bilbao-Vizcaya buoy (Puertos del Estado – http://www.puertos.es/en-us), whereas the wind data from the meteorological agency of Galicia (MeteoGalicia). This model, with a native resolution of 12 km, reproduces the offshore wind fields of the SE BoB with reasonable accuracy (Manso-Narvarte et al., 2018). Both wave and wind data were provided with an hourly average frequency. In contrast the wave and wind data for the French sampling was provided by the vessel Itsas Belhara F/V as onboard measurements.

Statistical analysis

All statistical analyses were performed using the software package MATLAB (version R2021a). Two set of analyses were performed: one considering all the data available regardless the administrative region, and the other separately for French and Spanish samples due to the temporal coverage differed for the sampling period, so did the spatial resolution. Data were tested for normality according to sample sizes by Shapiro-Wilk test (<50 samples) and Kolmogorov test (>50 samples). Since data were not normally distributed, the nonparametric Kruskal-Wallis test (K-W) was performed to identify the annual and monthly differences between plastic abundances and between sampling stations. Statistically relevant differences were considered when p-value <0.01. Spearman's rank correlation (SP) was used to test the correlation between abundances, the bathymetry and the distance to coastline. Likewise, Spearman's rank correlation was applied to get a better insight into the possible connections between particle abundance of macro-mesoplastics, meso-microplastics and macro- microplastics. The level of strong correlation was set up at $p \geq \pm 0.9$, following (Schober et al., 2018).

RESULTS

Spatial and temporal abundance

Plastic fragments were found in 100% of the samples, with a total of 195,330 plastic items found at the 40 stations. The highest abundance was observed in September 2019 along the French coast, with one sample presenting 23,560,179 items/km2 and 23.0 kg/km2.

Table 5.3. Neustonic plastic results for coastal waters of the SE BoB by year. Values correspond to the mean, standard deviation (SD), median, min and max values of the samples obtained in the 2017-2020 survey. The results include macro, meso and microplastic items. Observed data, no correction was applied to the data.

		2017	2018	2019	2020
Plastic items/km2	Mean	255,601	1,395,467	1,382,354	905,779
	(± SD)	347,919	3,547,757	4,370,379	3,087,516
	Median	169,453	323,219	444,196	256,081
	Min	33,614	54,244	103,194	82,753
	Max	2,526,181	20,580,976	23,560,179	18,369,193
	Micro	213,271	811,268	1,296,551	839,276
	(Aver. ± SD)	± 324,973	± 899,046	± 4,078,083	± 2,847,696
	Meso	12,021	70,422	94,791	61,928
	(Aver. ± SD)	± 31,989	± 121,738	± 282,470	± 232,622
	Macro	2,300	13,307	8,239	4,574
	(Aver. ± SD)	± 6,272	± 34,856	± 10,687	± 8,370
Plastic g(dw)/km2	Mean	312	1499	1238	2157
	(± SD)	934	3,376	4,325	8,552
	Median	40	420	186	150
	Min	1	17	3	4
	Max	7,047	15,329	22,982	50,012
	Micro	62	447	539	436
	(Aver. ± SD)	± 304	± 987	± 2,436	± 1,335
	Meso	60	300	468	421
	(Aver. ± SD)	± 187	± 682	± 1,799	± 1,248
	Macro	173	753	232	1,300
	(Aver. ± SD)	± 838	± 1,961	± 507	± 6,164

The abundances in the studied region were generally medium-high (Table 5.3), ranging from 33,614 to 23,560,179 items/km2, with average ± standard deviation (SD) values of 739,395 ± 2,625,271 items/km2 (median = 232,227 items/km2). The mass concentration of plastic fragments varied from 0.7 to 50,012 g/km2 (median = 74 g/km2, mean ± SD = 998 ± 4,338 g/km2). All months presented at least one sample with more than 1,000,000 items/km2, excluding October 2017, July 2019, June 2020, July 2020, and September 2020. Abundances are mapped in Figs 5.5-5.6, and monthly abundances and mass concentrations are shown in Fig 5.7. Detailed results are listed in Supplementary Table 5.6-5.7 per month and year of sampling and per station.

Significant abundance differences were found between Spanish and French data sets (Mann-Whitney, $p < 0.01$), French waters present almost 5 times more plastic than the one observed in Spanish waters. In the Spanish coast, the largest abundances were observed in the most eastern regions, close to the French waters.In the Spanish coast, the largest abundances were observed in the most eastern regions, close to the French waters. However, in November the largest abundances seem to be well spread throughout the sampling area, despite presenting the lowest abundances in the most westerly sampling stations, close to Deba River (Fig 5.5). In French waters the highest abundances were observed in the months of August and September with means of 1,928,036 ± 3,886,985 items/km2 (August) and 2,432,697 ± 6,549,578 items/km2 (September). Spatially, the area of Biarritz resulted the most predominant to accumulate plastic, followed by the area close to the Adour River (Fig 5.6). Nonetheless, statistically speaking, no further analysis could be performed to investigate the statistical differences between sampling stations, and thus, determine a potential local hotspot due to the population size for each sampling stations was too small (i.e. only 3 data per station, related to 3 years of study for French waters, and only 1 data per station for Spanish waters). According to size, microplastics were the most abundant for both Spanish (meanmicro= 213,271 ± 324,973 items/km2) and French waters (meanmicro = 963,020 ± 2,819,154 items/km2). Overall, mesoplastics (meanmeso= 46,259 ± 164,956 items/km2) were one order of magnitude higher than macroplastics (meanmacro ± SD = 5,781 ± 17,029 items/km2) and both were largely lower than microplastics (meanmicro= 624,562 ± 2,127,574 items/km2). There was no significant correlation between macro and mesoplastics, neither between macro and microplastics for both French and Spanish waters (Spearman test, $p<0.9$) (Table 2), or if the analysis was performed for all the data sets available regardless their administrative region. However, there was a strong positive correlation between French meso and microplastics abundance (Spearman test, pitems/km^2 =0.9496, pitems/m^3=0.9196, pg/km^2=0.9157, pg/m^3=0.8467) (Fig. 5). It should be noted that significant differences were detected between abundances observed in different years (i.e., when considering data from each year as a separate data set) (Kruskal-Wallis test $p<0.01$). Besides, when the Spanish data set was excluded from the analysis, the abundances did not show any significant differences either when the analysis was undertaken by years or by months (K–W test, $p>0.01$) (Table 2). However, the month-by-month analysis showed that significant differences were detected when abundances from Spanish locations were compared (K–W test, pitems/km^2=0.004, pitems/m^3 =0.0059, pg/km^2=1.998e-07, pg/m^3=1.225e-06); no significant differences were detected between French sampling stations (K-W test, $p>0.01$). No clear correlation was found between floating plastic abundance and the bathymetry or the distance to the coastline (ρ Spearman<0.9).

Composition of plastic items: type, size and colour

In terms of type of objects, fragments were the most common objects in the microplastic range, followed by fibres; in the case of mesoplastics, fragments, fishing lines and films represented almost 98% of the items, whereas fishing lines resulted the most common objects for macroplastics (Table 5.5).

As for colour, almost half of the plastic present in the study area was transparent, followed by white, black-grey, and green (this latter one only for meso- and macroplastics) (Table 5.5). Few quantities of blue items (6%), yellow/orange/brown (4%) and red/pink/purples (2%) were found in all ranges.

DISCUSSION

Plastic abundance in coastal SE BoB surface waters

Many numerical modelling studies underline that the BoB is a trapping zone for floating plastic (Rodríguez-Díaz et al., 2020; van Sebille et al., 2012). Others particularly point to the SE region as one of the most important aggregation areas within the BoB, especially in spring-summer seasons due to their seasonal wind and wave patterns (Declerck et al., 2019; Pereiro et al., 2018, 2019; Ruiz et al., 2022a), fact that is corroborated by scientific samplings (Ruiz et al., 2022b). However, most studies focus on oceanic waters, and coastal areas are left overlooked. The importance of analysing coastal waters has been stressed by some model simulations (Onink et al., 2021), which point at coastlines and coastal waters as important reservoirs of floating plastic. Morales-Caselles et al. (2021) compiled global-scale data to show state that most of the macrolitter entering the ocean from land-based sources is retained in the coastal strip, where it can create secondary microplastics by dif-ferent processes (Efimova et al., 2018). Here we demonstrate that the coastal waters of the SE BoB, especially in spring and summer months are indeed a neustonic plastic aggrega-tion area, with observed average microplastic abundances of 1,117,403 ± 3,808,626 items/km2. Abundances are slightly higher (756,865 items/km2) than those reported by Ruiz et al. (2022b) for the BoB.

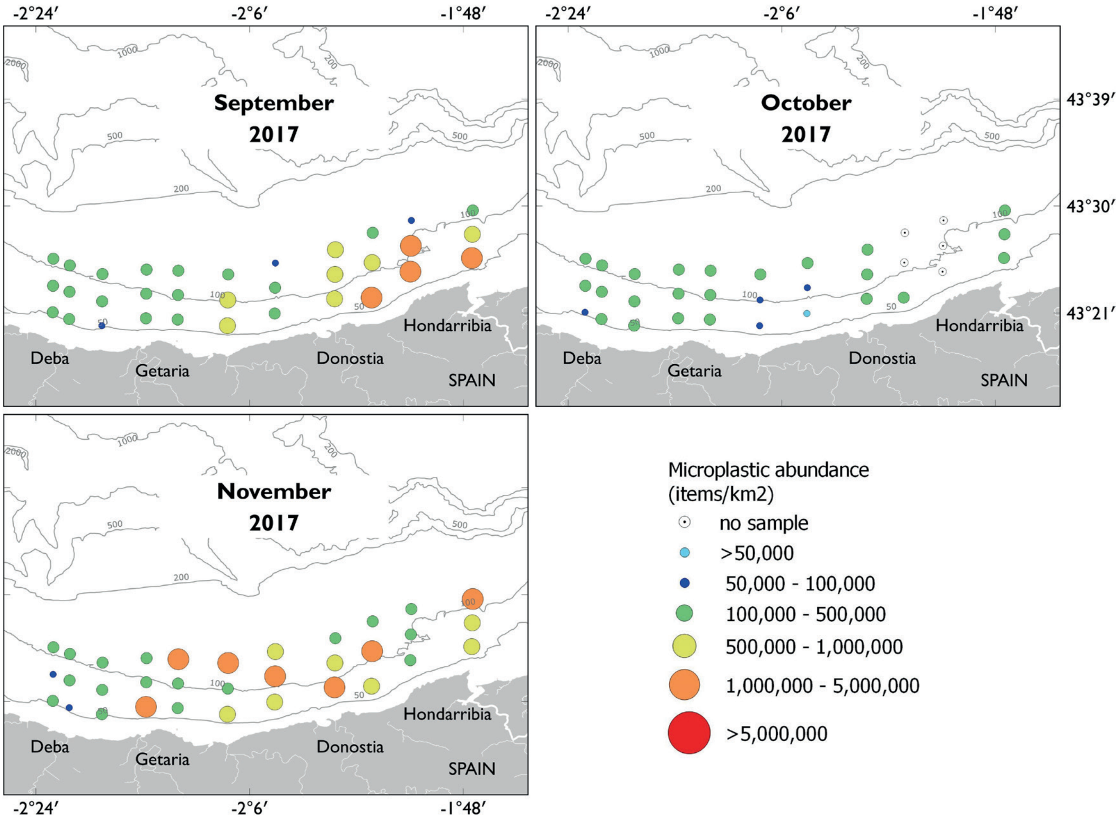


Fig 5.5. Plastic abundances (items/km2), in Spanish waters (data corrected by wind following Kukulka method)

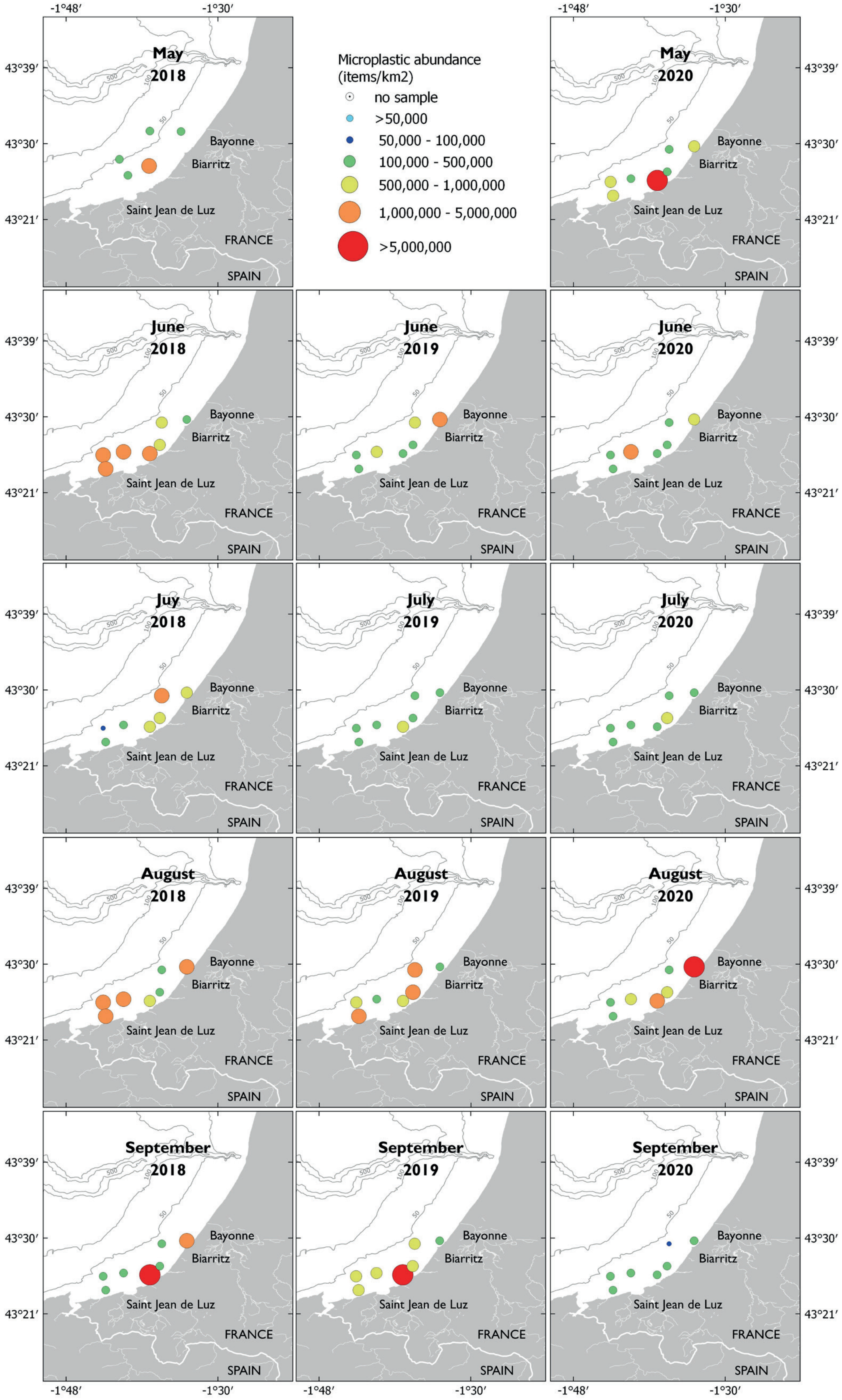


Fig 5.6. Plastic abundances (items/km2), in French waters (data corrected by wind following Kukulka method

Altogether the abundances in this region are 6-33 times higher than those reported by Gago et al. (2015) for the surface coastal waters of the SW BoB for 2013 and 2014 (34,000 and 176,000 items/km2). Also, they are higher than those observed by Frias et al. (2014) in Portuguese coastal waters (0.036 items/m3) versus 2.748 items/m3 of the present study. And higher than those reported for subtropical gyres and other coastal regions (Table 5.6).

Therefore, it seems appropriate to hypothesise the existence of a floating plastic gradient from coastal waters of the SE BoB towards the more westerly areas. There it is of utmost importance to not only increase the modelling effort in coastal areas but also the sampling efforts to improve the resolution of data. Marine litter and plastic abundances in coastal waters have been explored worldwide (some studies are shown in Table 5.6).

Table 5.4. Summary of statistical analysis performed for neustonic plastics at the coastal sampled areas. Temporal, spatial and size comparisons were made on particle abundance (items/km2, items/m3) and mass concentration (g/km2 and g/km3). In bold, statistically significant results (p-value <0.01 for K-W test, limit > 0.9 for SP test, as suggested by Schober et al. (2018).

Plastic abundance comparison	**Area**	**Period**	**Normality test**	**Statistical test**	**P items/km^2**	**P items/m^3**	**P g/km^2**	**P g/m^3**
By year	France	2018-2020	Shapiro-Wilk	K-W	0.0942	0.167	0.0554	0.0798
By month	France	2018-2020	Shapiro-Wilk	K-W	0.0585	0.0045	0.1394	0.0387
	Spain	2017	Shapiro-Wilk	K-W	0.004	0.0059	1.998e-7	1.225e-6
By sampling stations	France	2018-2020	Shapiro-Wilk	K-W	0.1235	0.1381	0.0259	0.0362
	Spain	2017	Shapiro-Wilk	-	Samples sizes were too small and the selection not representative			
By depth	France	2018-2020	Kolmogorov	SP	-0.0649	-0.0503	-0.1297	-0.1313
	Spain	2017	Kolmogorov	SP	0.0294	0.0324	0.0725	0.0783
By distance to coastline	France	2018-2020	Kolmogorov	SP	-0.1809	-0.1761	-0.2408	-0.2440
	Spain	2017	Kolmogorov	SP	-0.0725	-0.0754	0.0347	0.0462
Macro and microplastic abundance correlation	Spain	2017	Kolmogorov	SP	0.4548	0.2922	0.0477	0.0594
	France	2018-2020	Kolmogorov	SP	0.3523	0.3473	0.5376	0.5315
Macro and mesoplastic abundance correlation	Spain	2017	Kolmogorov	SP	0.8636	0.8882	0.1185	0.1619
	France	2018-2020	Kolmogorov	SP	0.5996	0.6694	0.5440	0.4694

The Mediterranean Sea, for example, in addition of being the largest European sea and semi-enclosed basin with dense coastal population, it is an accumulative basin for plastic litter (Cózar et al., 2015). The average abundances observed in the SE BoB are similar to those reported for coastal areas of the Mediterranean Sea.

In the Central and Western Mediterranean Sea, the observed average surface water microplastics abundance ranged from 347,783 ± 457,128 items/km2 in the coastal waters of the Menorca channel (Ruiz-Orejón et al., 2019) to circa 900,000 items/km2 (858,029 ± 4,082,964 items/km2 by Compa et al. (2020) and 900,324 ± 1,171,738 items/km2 by Ruiz-Orejón et al. (2018)) in the coastal waters of the Balearic Islands; and they were even slightly higher than those of the coastal western Mediterranean Sea (de Haan et al., 2019). Factors including boundary effects, discharge of large rivers, large coastal population, and tourism were proposed by these authors to explain the source and accumulation in coastal areas (Ruiz-Orejón et al., 2016).

However, their abundances were far from the 23,560,179 items/km2 observed in September 2019, near the coast of Saint Jean de Luz (France). Only van der Hal et al. (2017) observed such extreme concentrations near the coast of Israel (in the Eastern Mediterranean Sea) with a maximum of 64,812,600 particles/km2. This suggests that surface coastal waters of the SE BoB seem contaminated with slightly similar concentrations than those observed in the Mediterranean Sea. However, the heterogeneity in sample collection and processing methodologies and reporting makes the comparison between studies quite complex (Mendoza et al., 2020); this complexity get further increased when fibres are accounted as shown in section 5.2. Thus, it is of utmost importance to consider standardization of the sampling and analysis methods (Cole et al., 2011; Cowger et al., 2020; Galgani et al., 2010). The neuston net used in this study had a 500 μm mesh size net whereas most of the studies cited in the comparison used smaller mesh sizes. Nevertheless, an increase in the observed abundance would be expected if a smaller mesh size net (i.e., 335 μm) would be used.

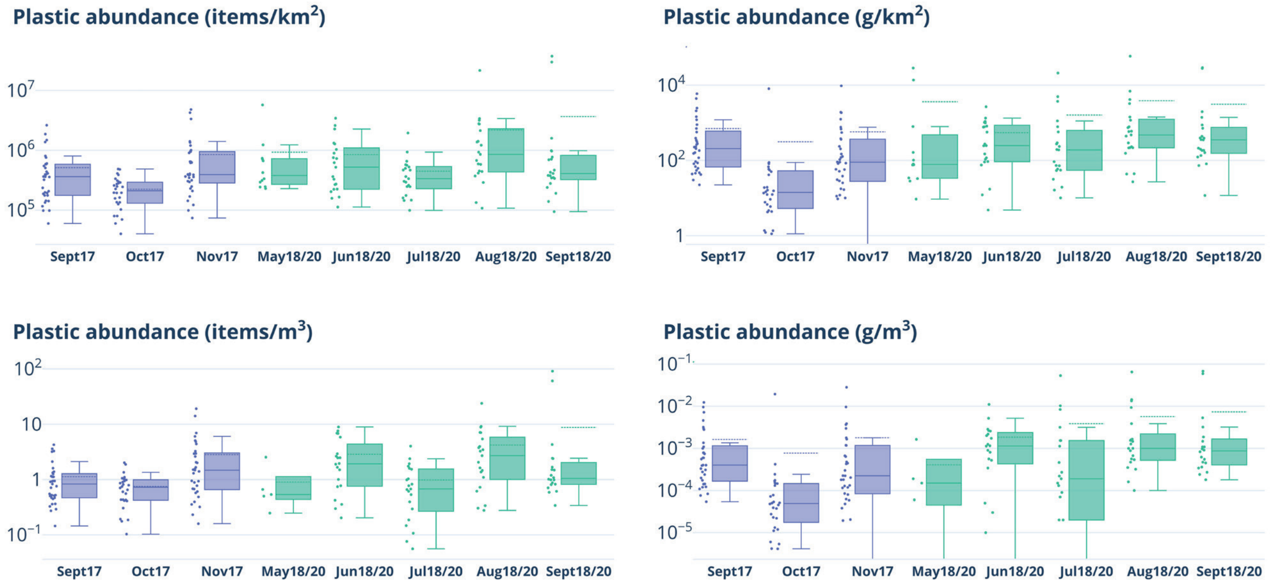


Fig 5.7. Comparison between years of plastic abundance for Spanish (blue, 2017) and French (green, 2018-2020) coastal waters in the SE BoB. Sample points are shown and solid lines into boxes indicate median values and broken lines indicate mean values, boxes indicate first and third quartiles, and whiskers indicate the minimum and maximum values.

In any case, the figures would still be higher than those reported by Ruiz et al. (2022b) as part of the BIOMAN survey for the surface waters of the BoB.

While a strong positive correlation between micro and mesoplastic concentrations was identified, it must be noted that the macroplastics concentration was not correlated to the smallest fractions. This result points to the fact that macroplastics behave differently to micro and mesoplastics, being their drift and retention probably driven by different physical processes linked for instance to their different buoyancy (e.g. the fraction of macroplastics with positive buoyancy would be much more influenced by the wind drag direct effect). From independent sampling conducted in the same area in summer 2018, Ruiz et al. (2020) demonstrated that floating marine litter tends to accumulate in marine litter windrows. During the neustonic sampling, several litter windrows were observed in French waters. Nonetheless, if a windrow was detected in the area, a nearby window-free area was selected as an alternative location to tow the

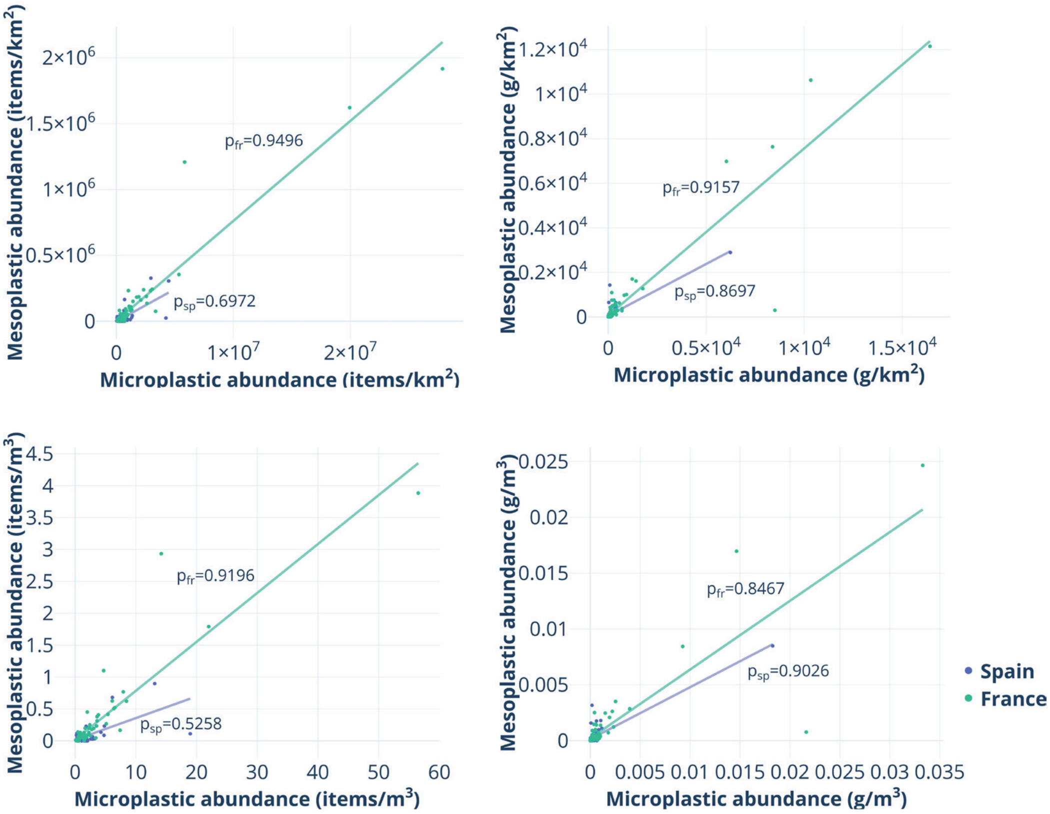


Fig 5.8. Correlation between micro and mesoplastics abundances and mass concentrations calculated from data of French and Spanish samples. Observed data, no correction was applied to the data.

Table 5.5. Frequency of type of objects and colours conforming the micro-, meso-, and microplastic item categories found in the plastic floating in the coastal waters of the SE BoB (results are given in %)

%	Microplastic	Mesoplastic	Macroplastic
	BY TYPE OF OBJECTS		
Fragments	69.9	41.1	7.6
Films	2.1	25.2	13.9
Pellets	0.4	1.7	-
Expanded polystyrene	4.0	0.5	-
Paints	1.9	-	-
Fishing lines	3.7	31.5	78.5
Fibres	16.9	-	-
Rubbery	0.7	-	-
Paraffins	0.2	-	-
	BY COLOURS		
White	18.4	15.9	14.4
Black, Grey	10.9	13.0	16.7
Transparent	51.7	44.4	33.3
Green	4.3	13.9	24.4
Blue	6.2	5.3	6.7
Red, Pink, Purple	3.0	2.5	1.7
Yellow, Orange, Brown	5.5	5.0	2.9

neuston net. This ensured that the net was not clogged or damaged and that results were not altered by sampling within an aggregation structure. Thus, while the sampling in Ruiz et al. (2020) focused on the windrows and macrolitter, here the neuston net was trawled in windrow-free waters. The difference between marine litter within windrows (mean ± SD=24,864,714 ± 26,159,598 g/km2 reported by Ruiz et al. (2020)) and windrow-free areas (i.e. neustonic sampling locations reported in the current paper) (mean ± SD=2,445 ± 8,008 g/km2) was very prominent during summer 2018. This evidences the striking contrast between plastic concentration within and beyond aggregation structures as well as the capacity of the windrows to retain floating plastics in the SE BoB. Thus, the need of studying these type of aggregation structures when assessing the overall plastic concentrations at sea, in order to avoid underestimation of ocean plastic. The correlation between the smallest fractions could also enable the extrapolation of mesoplastic pollution through the microplastics abundances. This correlation was also observed for the Mediterranean Sea (Faure et al., 2015). Unlike surface waters, Masiá et al. (2021) identified significant correlations between mesoplastics and macroplastics along the southwest beaches of BoB, highlighting that size correlation can differ between different marine compartments. The no-correlation between abundance and monthly sampling stations suggests that sampling stations may be under the same influence for plastic pollution; nonetheless, a wider dataset for the same sampling periods and years would be required to identify monthly and seasonal trends. As such, plastic contamination of the coastal waters of the SE BoB was observed to vary both spatially and temporally, especially between Spanish and French stations. . In relation to months, in French waters the spring-summer period months of August (1,928,036 items/km2) and September (2,432,697 items/km2) tended to present higher abundances and July the least (297,455 items/km2), whereas in Spanish waters November (327,017 items/km2) presented abundances in the order of May in French waters (429,558 items/km2). Several aspects are proposed to explain this difference. (1) The fact of having different seasons sampled in the analysis (France: Spring-Summer; Spain: autumn), may have affected the results. Nonetheless, neustonic sampling carried out within la Concha Bay in Donostia-San Sebastian (June 2021) by the authors, following the same methodology presented in this study, revealed average abundances 465,566 ± 174,935 items/km2 (165 ± 137 g/km2) (Larreta et al., 2021), slightly lower than the ones observed in French coastal waters. Thus, the sampling seasonality effect remains unproved. (2) The year 2018 presented the average highest abundance, which may be related to the fact of 2018 being a particularly rainy year, and consequently it may have led to an increase in the release of material from the rivers, including microplastic transported by the river plume. However, not significant differences were found amongst years and stations within each subregion (i.e., Spanish and French waters). Lastly, (3) French stations were located closer to the coast than Spanish ones. And although Pedrotti et al. (2016) observed the highest concentrations of microplastic within the 1 km of coastal water along the French Mediterranean coast, no statistically significant differences were observed between the abundances and the distance to shore.

Table 5.6. Reported microplastic abundances in surface waters for different seas around the world, including litter aggregation areas of the open ocean, using manta (M) or Neuston (N) nets.

Sampling area	Sampling location: Open ocean (OC), Coastal (C)	Abundance items/km2		Net mesh size (µm)	Reference
		Mean	Max		
Bay of Biscay					
South-East Bay of Biscay	C	739,395	23,560,179	N 500	Present work
Bay of Biscay	C, OC	363,732	3,476,222*	N 335	(Ruiz et al., 2022b)
Western Bay of Biscay	C	176,000		M 335	(Gago et al., 2015)
Atlantic Ocean					
North-East Atlantic	OC	36,623	375,854	M 333	(Maes et al., 2017)
North-Atlantic Ocean, Azores	C	173,811	467,260	M 200	(Herrera et al., 2020)
North-Atlantic Ocean, Madeira	C	69,626	124,190	M 200	(Herrera et al., 2020)
North-Atlantic Ocean, Canary Islands	C	194,951	1,007,872	M 200	(Herrera et al., 2020)
Mediterranean Sea					
North-West Med.	C	116,000	892,000	M 333	(Collignon et al., 2012)
North-West Med.	C	158,000	578,000	M 333	(Pedrotti et al., 2016)
West Med., Balearic Islands	C	900,324	4,576,115	M 333	(Ruiz-Orejón et al., 2018)
West Med., Mallorca	C	858,029		M 335	(Compa et al., 2020)
West Med., Spanish coast	C	108,000	500,000	M 335	(de Haan et al., 2019)
Central and West-Med., Adriatic Sea	C, OC	400,000	4,520,000	N 200	(Suaria et al., 2016)
Central and West-Med.	C, OC	147,500	1,164,403	M 333	(Ruiz-Orejón et al., 2016)
East Med. (Israeli coast)	C	1,518,384	64,812,600	M 333	(van der Hal et al., 2017)
All Mediterranean	OC	243,853		N 200	(Cózar et al., 2015)
Other regions					
Arctic (Greenland & Barents Seas)	OC, C	63,000	320,000	M 500	(Cózar et al., 2017)
Baltic Sea, Stockholm Archipelago	C	110,000	618,000	M 335	(Gewert et al., 2017)
Australia	C	4,256	33,412	N-M 335	(Reisser et al., 2013)
Hong Kong waters	C	334,780	1,675,982	M 333	Cheung et al., 2018)
Southern Ocean, Antarctica	OC	1719	39,096	N 200	(Suaria et al., 2020b)
Weddell Sea, Antarctica	OC	1,838		M 300	(Leistenschneider et al., 2021)
Accumulation zones (gyres)					
North Atlantic gyre	OC		580,000	N 335	(Law et al., 2010)
North-East Pacific gyre	OC	209,010	4,188,092	M 500	(Egger et al., 2020)
South Pacific gyre	OC	26,988	396,342	M 333	(Eriksen et al., 2013)

*This figure has been calculated by the authors from the data collected in the BIOMAN survey (2017-2019), which results are shown in Ruiz et al. (2022b), contribution that shares authorship with the present contribution.

Composition of the observed neustonic plastic

Microplastic accounted for 92% of the neustonic plastics collected on the surface of the SE BoB, in line with the findings for the BoB southern waters (Carretero et al., 2022; Gago et al., 2015). Regarding the type of items, a large proportion of microplastics were plastic fragments (69.9%), consistent with previous studies published for other European regions (Adamopoulou et al., 2021; Faure et al., 2015; Maes et al., 2017). The type of object does not allow making clear statements about the origin of the particles, though plastic fragments were probably derived from the fragmentation of larger objects, favored by continuous beaching and resuspension along Spanish and French coastal areas. Fibers (16.9%) were in the lower range of data reported for the Baltic Sea (Gewert et al., 2017) or the Atlantic Ocean (Kanhai et al., 2017). Fibres can be generated from a number of sources. They can be derived from washing textiles and enter the ocean via wastewater (De Falco et al., 2019; Gaylarde et al., 2021; Salvador Cesa et al., 2017) or they can be originated from sea-based conventional activities such as fishing (Lusher et al., 2017; Xue et al., 2020). Despite fibres are regarded as a prevalent type of microplastic, few studies dealing specifically with this type of item are scarce. Besides, distinction between natural and synthetic fibres during lab sampling process is not always conducted so further identification accuracy is needed to draw any firm conclusion on fibres abundance comparison (Suaria et al., 2020a). In the present contribution all fibres were considered to be synthetic, and no FTIR was applied to define the origin. Plastics were mainly transparent, followed by white and grey/black colored items, similar to those found in and Black Sea and Caspian Sea basins (D'Hont et al., 2021) and the Western Mediterranean sea (de Haan et al., 2019). However, colour comparison and relevance of this information is limited by methodology or observer subjectivity (Martí et al., 2020).

Origin and distribution of the observed plastic

LIFE LEMA project was proposed to implement an effective way of managing floating marine litter in the SE BoB. A deeper understanding of plastic distribution and concentration was necessary to target the sites exposed to this pollution. This has been addressed as part of several contributions targeting microplastics in the BoB (Mendoza et al., 2020), floating marine litter abundance as part of ecosystemic surveys (Ruiz et al., 2022b), aggregation of floating marine litter in coastal marine litter windrows (Ruiz et al., 2020), modelling of plastic sea surface distribution having rivers as sources (Declerck et al., 2019), modelling of fishing activity related floating marine litter (Ruiz et al., 2022a), floating marine litter collection solutions (Andrés et al., 2021), and beaching forecasts for efficient cleaning services (Granado et al., 2019). The present contribution provides the needed information regarding Neustonic plastic abundance and distribution, and it complements the overall picture. The backtracking approach of the observed microplastics particles is proposed as particularly useful for local authorities to tackle the problem at its source.

CONCLUSIONS

This study demonstrates that the south-eastern Bay of Biscay (SE BoB) is a dead-end for plastic and it shows that plastic pollution levels in coastal waters of the SE BoB are similar to those in the Mediterranean Sea. Neustonic plastic samples have been collected from 40 stations in four years (2017-2020) across the SE BoB in Spanish and French coastal waters. SE French Atlantic coast seems more prone to accumulate microplastics than Spanish neighboring region, especially in spring-summer months. The region presents an average abundance of 739,395 ± 2,625,271 items/km2 (998 ± 4,338 g/km2) and a median of 232,227 items/km2 (74 g/km2). French coast was mostly affected (with 5 times higher plastic abundances than in the Spanish coast), with an average of 1,213,110 ± 3,624,181 items/km2 in 2018-2020, whereas in the Spanish counterpart (which are neighbouring areas) averages of 255,601 ± 347,919 items/km2. Microplastic represented 94% of the plastic items in the samples, mesoplastic 5 % and macroplastic 1% (in terms of weight the share was 47% microplastics, 31% mesoplastic, 22% macroplastic). The most common items collected were fragments and fibres in the microplastic range; fragments, fishing lines and films represented almost the 98% of the items for mesoplastics; and fishing lines for macroplastics. As for colour, almost half of the plastic present in the study area was transparent, followed by white, black-grey, and green (this latter one only for meso- and macroplastics). Micro- and mesoplastic abundance and mass concentrations showed a positive correlation. None was found for macrolitter, suggesting that macrolitter may be governed by different physical processes (Morales-Caselles et al., 2021). Neustonic sampling must be combined with marine litter windrows analysis to be able to estimate the floating marine litter concentration. Our results reinforce the importance of having local authorities setting solutions to prevent the entry of plastics and their seasonal formation.

ACKNOWLEDGEMENTS

This project has been partially funded through the LIFE Program (LIFE LEMA project, grant agreement no. LIFE15 ENV/ES/000252), EU's Horizon 2020 research and innovation programme under grant agreement No 654410 (JERICO-NEXT project). The authors are thankful to the skippers and crews of fishing vessels Itsas Belhara and Miren Argia for their invaluable knowledge and help during the surveys. T. Destang and I. Ruiz were supported by AZTI, the first with a placement scholarship for his MSc thesis (European MSc in Marine Environment and Resources) and the later (I. Ruiz) with a PhD fellowship. We also would like to thank I. Granado, I. Martin, G. Bidegain for their assistance during the sampling. This paper is contribution nº xxx AZTI-Marine Research (BRTA).

AUTHORS CONTRIBUTION

O.C. Basurko: conceptualization, sampling, data analysis, investigation methodology, writing original draft, supervision, and funding acquisition; I. Ruiz: sampling, statistical analysis, validation, review and editing; A. Rubio: conceptualization, investigation methodology, modelling supervision, writing validation, review and editing; B. Beldarrain: laboratory analysis and sampling; D. Kukul: laboratory analysis; M. Galli: laboratory analysis; A. Cozar: methodology, review and editing; T Destang: laboratory analysis, data analysis; J. Larreta: conceptualization, investigation methodology, validation, review and editing.

References

Adamopoulou, A., Zeri, C., Garaventa, F., Gambardella, C., Ioakeimidis, C., Pitta, E., 2021. Distribution Patterns of Floating Microplastics in Open and Coastal Waters of the Eastern Mediterranean Sea (Ionian, Aegean, and Levantine Seas). Frontiers in Marine Science 8.

Andrés, M., Delpey, M., Ruiz, I., Declerck, A., Sarrade, C., Bergeron, P., Basurko, O.C., 2021. Measuring and comparing solutions for floating marine litter removal: Lessons learned in the south-east coast of the Bay of Biscay from an economic perspective. Mar. Pol. 127, 104450.

Borja, A., Amouroux, D., Anschutz, P., Gómez-Gesteira, M., Uyarra, M.C., Valdés, L., 2019. Chapter 5 - The Bay of Biscay, in: Sheppard, C. (Ed.), World Seas: an Environmental Evaluation (Second Edition). Academic Press, pp. 113-152.

Borja, A., Elliott, M., 2019. So when will we have enough papers on microplastics and ocean litter? Marine Pollution Bulletin 146, 312-316.

Capolupo, M., Sørensen, L., Jayasena, K.D.R., Booth, A.M., Fabbri, E., 2020. Chemical composition and ecotoxicity of plastic and car tire rubber leachates to aquatic organisms. Water Research 169, 115270.

Carretero, O., Gago, J., Filgueiras, A.V., Viñas, L., 2022. The seasonal cycle of micro and meso-plastics in surface waters in a coastal environment (Ría de Vigo, NW Spain). Science of The Total Environment 803, 150021.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62, 2588-2597.

Collignon, A., Hecq, J.-H., Glagani, F., Voisin, P., Collard, F., Goffart, A., 2012. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. Marine Pollution Bulletin 64, 861-864.

Compa, M., Alomar, C., Mourre, B., March, D., Tintoré, J., Deudero, S., 2020. Nearshore spatio-temporal sea surface trawls of plastic debris in the Balearic Islands. Marine Environmental Research 158, 104945.

Cowger, W., Booth, A.M., Hamilton, B.M., Thaysen, C., Primpke, S., Munno, K., Lusher, A.L., Dehaut, A., Vaz, V.P., Liboiron, M., Devriese, L.I., Hermabessiere, L., Rochman, C., Athey, S.N., Lynch, J.M., De Frond, H., Gray, A., Jones, O.A.H., Brander, S., Steele, C., Moore, S., Sanchez, A., Nel, H., 2020. Reporting Guidelines to Increase the Reproducibility and Comparability of Research on Microplastics. Applied Spectroscopy 74, 1066-1077.

Cózar, A., Aliani, S., Basurko, O.C., Arias, M., Isobe, A., Topouzelis, K., Rubio, A., Morales-Caselles, C., 2021. Marine Litter Windrows: A Strategic Target to Understand and Manage the Ocean Plastic Pollution. Frontiers in Marine Science 8.

Cózar, A., Martí, E., Duarte, C.M., García-de-Lomas, J., van Sebille, E., Ballatore, T.J., Eguíluz, V.M., González-Gordillo, J.I., Pedrotti, M.L., Echevarría, F., Troublè, R., Irigoien, X., 2017. The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. Science Advances 3.

Cózar, A., Sanz-Martín, M., Martí, E., González-Gordillo, J.I., Ubeda, B., Gálvez, J.Á., Irigoien, X., Duarte, C.M., 2015. Plastic Accumulation in the Mediterranean Sea. PLoS ONE 10, e0121762.

Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel, S., Batifoulier, F., Dumas, F., Pichon, A., Morel, Y., 2013. Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay. Journal of Marine Systems 109-110, S60-S76.

Cheung, P.K., Fok, L., Hung, P.L., Cheung, L.T.O., 2018. Spatio-temporal comparison of neustonic microplastic density in Hong Kong waters under the influence of the Pearl River Estuary. Science of The Total Environment 628-629, 731-739.

D'Hont, A., Gittenberger, A., Leuven, R.S.E.W., Hendriks, A.J., 2021. Dropping the microbead: Source and sink related microplastic distribution in the Black Sea and Caspian Sea basins. Marine Pollution Bulletin 173, 112982.

De Falco, F., Di Pace, E., Cocca, M., Avella, M., 2019. The contribution of washing processes of synthetic clothes to microplastic pollution. Scientific Reports 9, 6633.

de Haan, W.P., Sanchez-Vidal, A., Canals, M., 2019. Floating microplastics and aggregate formation in the Western Mediterranean Sea. Marine Pollution Bulletin 140, 523-535.

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, 1-15.

Efimova, I., Bagaeva, M., Bagaev, A., Kileso, A., Chubarenko, I.P., 2018. Secondary Microplastics Generation in the Sea Swash Zone With Coarse Bottom Sediments: Laboratory Experiments. Frontiers in Marine Science 5.

Egger, M., Nijhof, R., Quiros, L., Leone, G., Royer, S.-J., McWhirter, A.C., Kantakov, G.A., Radchenko, V.I., Pakhomov, E.A., Hunt, B.P.V., Lebreton, L., 2020. A spatially variable scarcity of floating microplastics in the eastern North Pacific Ocean. Environmental Research Letters 15, 114056.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S., 2013. Plastic pollution in the South Pacific subtropical gyre. Marine Pollution Bulletin 68, 71-76.

Faure, F., Saini, C., Potter, G., Galgani, F., de Alencastro, L.F., Hagmann, P., 2015. An evaluation of surface micro- and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea. Environmental Science and Pollution Research 22, 12190-12197.

Frias, J.P.G.L., Otero, V., Sobral, P., 2014. Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. Marine Environmental Research 95, 89-95.

Gago, J., Henry, M., Galgani, F., 2015. First observation on neustonic plastics in waters off NW Spain (spring 2013 and 2014). Marine Environmental Research 111, 27-33.

Galgani, F., Fleet, D., Van Franeker, J., Katsanevakis, S., Maes, T., Mouat, J., Oosterbaan, L., Poitou, I., Hanke, G., Thompson, R., Amato, E., Birkun, A., Janssen, C., 2010. Marine Strategy Framework Directive – Task Group 10 Report Marine litter, JRC Scientiftic and Technical Reports, Prepared under the Administrative Arrangement between JRC and DG ENV (no 31210 – 2009/2010), the Memorandum of Understanding between the European Commission and ICES managed by DG MARE, and JRC's own institutional funding, p. 57.

Gaylarde, C., Baptista-Neto, J.A., da Fonseca, E.M., 2021. Plastic microfibre pollution: how important is clothes' laundering? Heliyon 7, e07105.

Gewert, B., Ogonowski, M., Barth, A., MacLeod, M., 2017. Abundance and composition of near surface microplastics and plastic debris in the Stockholm Archipelago, Baltic Sea. Marine Pollution Bulletin 120, 292-302.

Granado, I., Basurko, O.C., Rubio, A., Ferrer, L., Hernández-González, J., Epelde, I., Fernandes, J.A., 2019. Beach litter forecasting on the south-eastern coast of the Bay of Biscay: A bayesian networks approach. Continental Shelf Research 180, 14-23.

Herrera, A., Raymond, E., Martínez, I., Álvarez, S., Canning-Clode, J., Gestoso, I., Pham, C.K., Ríos, N., Rodríguez, Y., Gómez, M., 2020. First evaluation of neustonic microplastics in the Macaronesian region, NE Atlantic. Marine Pollution Bulletin 153, 110999.

Huthnance, J.M., 1986. The Rockall slope current and shelf-edge processes. Proceedings of the Royal Society of Edinburgh. Section B. Biological Sciences 88, 83-101.

Kanhai, L.D.K., Officer, R., Lyashevska, O., Thompson, R.C., O'Connor, I., 2017. Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean. Marine Pollution Bulletin 115, 307-314.

Kesy, K., Oberbeckmann, S., Kreikemeyer, B., Labrenz, M., 2019. Spatial Environmental Heterogeneity Determines Young Biofilm Assemblages on Microplastics in Baltic Sea Mesocosms. Frontiers in Microbiology 10.

Kooi, M., Nes, E.H.v., Scheffer, M., Koelmans, A.A., 2017. Ups and Downs in the Ocean: Effects of Biofouling on Vertical Transport of Microplastics. Environmental Science & Technology 51, 7963-7971.

Kukulka, T., Proskurowski, G., Morét-Ferguson, S., Meyer, D.W., Law, K.L., 2012. The effect of wind mixing on the vertical distribution of buoyant plastic debris. Geophysical Research Letters 39.

Laiz, I., Ferrer, L., Plomaritis, T.A., Charria, G., 2014. Effect of river runoff on sea level from in-situ measurements and numerical models in the Bay of Biscay. Deep Sea Research Part II: Topical Studies in Oceanography 106, 49-67.

Larreta, J., González, M., Rubio, A., Basurko, O.C., 2021. Análisis de la abundancia y distribución de plásticos en la bahía de la Concha, AZTI's study for the Donostia-San Sebastian City Council. Pasaia, October 2021, p. 54.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic Accumulation in the North Atlantic Subtropical Gyre. Science 329, 1185-1188.

Lebreton, L.C.M., Greer, S.D., Borrero, J.C., 2012. Numerical modelling of floating debris in the world's oceans. Marine Pollution Bulletin 64, 653-661.

Leistenschneider, C., Burkhardt-Holm, P., Mani, T., Primpke, S., Taubner, H., Gerdts, G., 2021. Microplastics in the Weddell Sea (Antarctica): A Forensic Approach for Discrimination between Environmental and Vessel-Induced Microplastics. Environmental Science & Technology 55, 15900-15911.

Lusher, A.L., Hollman, P.C.H., Mendoza-Hill, J.J., 2017. Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety, Rome, Italy, p. 147.

Maes, T., Perry, J., Alliji, K., Clarke, C., Birchenough, S.N.R., 2019. Shades of grey: Marine litter research developments in Europe. Marine Pollution Bulletin 146, 274-281.

Maes, T., Van der Meulen, M.D., Devriese, L.I., Leslie, H.A., Huvet, A., Frère, L., Robbens, J., Vethaak, A.D., 2017. Microplastics Baseline Surveys at the Water Surface and in Sediments of the North-East Atlantic. Frontiers in Marine Science 4.

Manso-Narvarte, I., Caballero, A., Rubio, A., Dufau, C., Birol, F., 2018. Joint analysis of coastal altimetry and high-frequency (HF) radar data: observability of seasonal and mesoscale ocean dynamics in the Bay of Biscay. Ocean Sci. 14, 1265-1281.

Martí, E., Martin, C., Galli, M., Echevarría, F., Duarte, C.M., Cózar, A., 2020. The Colors of the Ocean Plastics. Environmental Science & Technology 54, 6594-6601.

Masiá, P., Ardura, A., Gaitán, M., Gerber, S., Rayon-Viña, F., Garcia-Vazquez, E., 2021. Maritime ports and beach management as sources of coastal macro-, meso-, and microplastic pollution. Environmental Science and Pollution Research 28, 30722-30731.

Masura, J., Baker, J., Foster, G., Arthur, C., 2015. Masura, J., et al. 2015. Laboratory method for the analisis of microplasticos in the marine environment: recommendations for quantifying synthetic particles in water and sediments., p. 31.

Mendoza, A., Osa, J.L., Basurko, O.C., Rubio, A., Santos, M., Gago, J., Galgani, F., Peña-Rodriguez, C., 2020. Microplastics in the Bay of Biscay: An overview. Marine Pollution Bulletin 153, 110996.

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S., Basurko, O.C., Mallos, N., Lebreton, L., Echevarría, F., van Emmerik, T., Duarte, C.M., Gálvez, J.A., van Sebille, E., Galgani, F., García, C.M., Ross, P.S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., Cózar, A., 2021. An inshore–offshore sorting system revealed from global classification of ocean litter. Nature Sustainability 4, 484-493.

Morichon, D., Dailloux, D., Aarninkhof, S., Abadie, S., 2008. Using a Shore-Based Video System to Hourly Monitor Storm Water Plumes (Adour River, Bay of Biscay). Journal of Coastal Research 24, 133-140.

Onink, V., Jongedijk, C.E., Hoffman, M.J., van Sebille, E., Laufkötter, C., 2021. Global simulations of marine plastic transport show plastic trapping in coastal zones. Environmental Research Letters 16, 064053.

Pedrotti, M.L., Petit, S., Elineau, A., Bruzaud, S., Crebassa, J.-C., Dumontet, B., Martí, E., Gorsky, G., Cózar, A., 2016. Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land. PLoS ONE 11, e0161581.

Pereiro, D., Souto, C., Gago, J., 2018. Calibration of a marine floating litter transport model. Journal of Operational Oceanography 11, 125-133.

Pereiro, D., Souto, C., Gago, J., 2019. Dynamics of floating marine debris in the northern Iberian waters: A model approach. Journal of Sea Research 144, 57-66.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B.D., Proietti, M., Thums, M., Pattiaratchi, C., 2013. Marine Plastic Pollution in Waters around Australia: Characteristics, Concentrations, and Pathways. PLoS ONE 8, e80466.

Rodríguez-Díaz, L., Gómez-Gesteira, J.L., Costoya, X., Gómez-Gesteira, M., Gago, J., 2020. The Bay of Biscay as a trapping zone for exogenous plastics of different sizes. Journal of Sea Research 163, 101929.

Rubio, A., Hernández-Carrasco, I., Orfila, A., González, M., Reyes, E., Corgnati, L., Berta, M., Griffa, A., Mader, J., 2020. A Lagrangian approach to monitor local particle retention conditions in coastal areas. In: Copernicus Marine Service Ocean State Report, Issue 4, Journal of Operational Oceanography, pp. S1-S172.

Ruiz-Orejón, L.F., Mourre, B., Sardá, R., Tintoré, J., Ramis-Pujol, J., 2019. Quarterly variability of floating plastic debris in the marine protected area of the Menorca Channel (Spain). Environmental Pollution 252, 1742-1754.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2016. Floating plastic debris in the Central and Western Mediterranean Sea. Marine Environmental Research 120, 136-144.

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, 636-646.

Ruiz, I., Abascal, A.J., Basurko, O.C., Rubio, A., 2022a. Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas. Environmental Pollution 292, 118216.

Ruiz, I., Basurko, O.C., Rubio, A., Delpey, M., Granado, I., Declerck, A., Mader, J., Cózar, A., 2020. Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter. Frontiers in Marine Science 7.

Ruiz, I., Burgoa, I., Santos, M., Basurko, O.C., García-Barón, I., Louzao, M., Beldarrain, B., Kukul, D., Valle, C., Uriarte, A., Rubio, A., 2022b. First assessment of floating marine litter abundance and distribution in the Bay of Biscay from an integrated ecosystem survey. Marine Pollution Bulletin 174, 113266.

Salvador Cesa, F., Turra, A., Baruque-Ramos, J., 2017. Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings. Science of The Total Environment 598, 1116-1129.

Schober, P., Boer, C., Schwarte, L.A., 2018. Correlation Coefficients: Appropriate Use and Interpretation. Anesth Analg 126, 1763-1768.

Shen, M., Ye, S., Zeng, G., Zhang, Y., Xing, L., Tang, W., Wen, X., Liu, S., 2020. Can microplastics pose a threat to ocean carbon sequestration? Marine Pollution Bulletin 150, 110712.

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

Suaria, G., Achtypi, A., Perold, V., Lee, J.R., Pierucci, A., Bornman, T.G., Aliani, S., Ryan, P.G., 2020a. Microfibers in oceanic surface waters: A global characterization. Science Advances 6, eaay8493.

Suaria, G., Avio, C.G., Mineo, A., Lattin, G.L., Magaldi, M.G., Belmonte, G., Moore, C.J., Regoli, F., Aliani, S., 2016. The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. Scientific Reports 6, 37551.

Suaria, G., Perold, V., Lee, J.R., Lebouard, F., Aliani, S., Ryan, P.G., 2020b. Floating macro- and microplastics around the Southern Ocean: Results from the Antarctic Circumnavigation Expedition. Environment International 136, 105494.

Tiller, R., Arenas, F., Galdies, C., Leitão, F., Malej, A., Romera, B.M., Solidoro, C., Stojanov, R., Turk, V., Guerra, R., 2019. Who cares about ocean acidification in the Plasticene? Ocean & Coastal Management 174, 170-180.

Van Acoleyen, M., Laureysens, I., Lambert, S., Raport, L., Van Sluis, C., Kater, B., van Onselen, E., Veiga, J., Ferreira, M., 2013. Final report - Marine Litter study to support the establishment of an initial quantitative headline reduction target - SFRA0025. European Commission DG Environment, p. 315.

van der Hal, N., Ariel, A., Angel, D.L., 2017. Exceptionally high abundances of microplastics in the oligotrophic Israeli Mediterranean coastal waters. Marine Pollution Bulletin 116, 151-155.

van Sebille, E., England, M.H., Froyland, G., 2012. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environmental Research Letters 7, 044040.

Xue, B., Zhang, L., Li, R., Wang, Y., Guo, J., Yu, K., Wang, S., 2020. Underestimated Microplastic Pollution Derived from Fishery Activities and “Hidden” in Deep Sediment. Environmental Science & Technology 54, 2210-2217.

Supplementary material

Supplementary Table 5.5

Supplementary Table 5.5. Sampling effort. Samples collected during the neustonic plastic surveys 2017-2020

Year	Sampling month	Sampling date	Number of samples	Sampled stations*$_1$	Average wind speed (m.s^{-1})*$_2$	Average wave height (m)*$_2$
2017 Spanish coastline	September	13/09/2017	7	29, 32, 33, 35, 36, 38, 39	4.66	2.05
		18/09/2017	8	17, 18, 21, 23, 24, 26, 27, 30	4.05	1.10
		19/09/2017	10	8, 9, 10, 11, 12, 13, 14, 15, 16, 20,	2.98	0.84
		20/09/2017	6	19, 22, 25, 28, 31, 34	5.26	0.83
		22/09/2017	2	37, 40	3.01	1.20
	October	10/10/2017	6	20, 21, 23, 24, 26, 27	3.91	0.59
		11/10/2017	6	8, 9, 10, 11, 13, 14	5.84	0.88
		12/10/2017	7	12, 15, 16, 17, 18, 19, 22	4.09	1.64
		13/10/2017	6	25, 28, 29, 30, 31, 32	3.16	1.46
		27/10/2017	3	38, 39, 40	4.17	1.15
	November	20/11/2017	10	8, 9, 10, 11, 12, 13, 14, 15, 16, 17	4.65	0.74
		21/11/2017	7	18, 19, 22, 25, 28, 31, 34	8.14	1.06
		22/11/2017	7	32, 35, 36, 37, 38, 39, 40	12.67	1.19
		23/11/2017	5	26, 27, 29, 30, 33	11.73	2.03
		24/11/2017	4	20, 21, 23, 24	8.55	1.75
2018 French coastline	May	31/05/2018	5	1, 2, 3, 5, 7	2.26	1.37
	June	20/06/2018	7	1-7	2.01	1.36
	July	18/07/2018	7	1-7	3.61	1.63
	August	08/08/2018	7	1-7	2.19	1.01
	September	05/09/2018	7	1-7	3.58	1.52
2019 French coastline	June	13/06/2019	7	1-7	2.54	1.24
	July	18/07/2019	7	1-7	3.39	1.12
	August	06/08/2019	7	1-7	1.08	1.03
	September	04/09/2019	7	1-7	4.34	0.87
2020 French coastline	May	26/05/2020	7	1-7	6.00	1.68
	June	23/06/2020	7	1-7	3.92	1.49
	July	23/07/2020	7	1-7	4.92	0.64
	August	12/08/2020	7	1-7	3.61	0.75
	September	08/09/2020	7	1-7	2.04	1.15

*$_1$ Sample station numbers are related to the ones shown in Fig1 of the manuscript.

*$_2$ Wind speed (at 10 m height) and Wave height are given as daily average from hourly modelled data for the Spanish coastline dataset. The data for French coastline were collected by onboard measurements.

Supplementary Table 5.6

Supplementary Table 5.6. Neustonic plastic abundances and weight densities in the coastal waters of the SE Bay of Biscay. Values correspond to (n=191; 95 in Spanish coastal waters and 96 in French coastal waters). SD: standard deviation; dw: dry weight. Observed data, no corrections have been applied to the abundance and densities.

Sampling month			**Particle abundance**		**Abundance weight**	
			items/km^2	items/m^3	g (dw)/km^2	g (dw)/m^3
September 2017 (Sp)	Mean		281,304	1.126	388	1.6E-03
		(± SD)	215,924	(1.030)	665	(2.9E-03)
	Median		237,354	0.830	136	4.0E-04
	Min		40,139	0.145	15	5.4E-05
	Max		1,046,619	4.254	2,950	1.2E-02
	Micro	Mean	NA	NA	NA	NA
		(± SD)	NA	NA	NA	NA
	Meso	Mean	NA	NA	NA	NA
		(± SD)	NA	NA	NA	NA
	Macro	Mean	NA	NA	NA	NA
		(± SD)	NA	NA	NA	NA
October 2017 (Sp)	Mean		141,138	0.752	267	7.7E-04
		(± SD)	78,841	0.467	1,329	3.6E-03
	Median		126,037	0.726	9	4.9E-05
	Min		35,256	0.103	1	4.1E-06
	Max		317,822	2.012	7,047	1.9E-02
	Micro	Mean	218,867	0.736	15	4.8E-05
		(± SD)	123,171	(0.468)	20	(8.0E-05)
	Meso	Mean	4,578	0.015	10	3.0E-05
		(± SD)	4,462	(0.017)	14	(4.0E-05)
	Macro	Mean	290	0.001	287	6.9E-04
		(± SD)	757	(0.002)	1,517	(3.7E-03)
November 2017 (Sp)	Mean		327,017	2.823	272	1.8E-03
	(± SD)		531,528	(4.006)	766	(5.1E-03)
	Median		172,144	1.476	37	2.2E-04
	Min		33,614	0.159	3	0.0E+00
	Max		2,526,181	19.074	4,135	2.8E-02
	Micro	Mean	808,162	2.692	255	7.7E-04
		(± SD)	1,067,235	(3.856)	1,076	(3.2E-03)
	Meso	Mean	34,362	0.115	162	4.9E-04
		(± SD)	78,376	(0.259)	512	(1.5E-03)
	Macro	Mean	4,890	0.017	158	5.2E-04
		(± SD)	12,364	(0.045)	366	(1.4E-03)
May 2018 (Fr)	Mean		384,772	0.897	183	4.2E-04
	(± SD)		389,437	(0.930)	287	(6.8E-04)
	Median		228,479	0.536	66	1.5E-04
	Min		189,929	0.247	22	5.8E-05
	Max		1,080,504	2.538	694	1.6E-03
	Micro	Mean	434,129	0.980	70	1.7E-04
		(± SD)	387,508	(0.890)	102	(2.3E-04)
	Meso	Mean	29,138	0.071	108	2.7E-04
		(± SD)	41,491	(0.095)	209	(4.8E-04)
	Macro	Mean	3,448	0.008	38	6.1E-05
		(± SD)	2,410	(0.005)	30	(5.3E-05)

June 2018 (Fr)	Mean		1,282,349	4.004	490	1.5E-03
	(± SD)		797,656	(2.697)	296	(1.0E-03)
	Median		1,169,668	2.924	502	1.3E-03
	Min		311,966	0.744	141	3.4E-04
	Max		2,418,751	7.588	833	2.8E-03
	Micro	Mean	1,527,987	3.737	308	7.7E-04
		(± SD)	1,104,018	(2.551)	221	(5.6E-04)
	Meso	Mean	94,998	0.242	182	4.6E-04
		(± SD)	78,287	(0.207)	177	(4.6E-04)
	Macro	Mean	9,819	0.025	127	3.0E-04
		(± SD)	6,351	(0.017)	159	(3.5E-04)
July 2018 (Fr)	Mean		369,934	1.554	2,564	1.1E-02
	(± SD)		368,237	(1.324)	4,295	(1.9E-02)
	Median		319,814	1.537	635	3.2E-03
	Min		54,244	0.294	17	9.4E-05
	Max		1,115,911	4.024	11,988	5.3E-02
	Micro	Mean	600,047	1.437	1,500	3.7E-03
		(± SD)	571,167	(1.185)	3,117	(7.9E-03)
	Meso	Mean	41,745	0.095	381	8.7E-04
		(± SD)	64,407	(0.132)	609	(1.3E-03)
	Macro	Mean	8,637	0.021	2,601	6.3E-03
		(± SD)	6,844	(0.015)	4,406	(1.1E-02)
August 2018 (Fr)	Mean		1,436,984	3.817	1,368	3.4E-03
	(± SD)		1,249,547	(3.433)	2,221	(5.0E-03)
	Median		1,048,380	2.702	640	1.5E-03
	Min		120,136	0.304	39	9.9E-05
	Max		3,120,372	9.160	6,348	1.4E-02
	Micro	Mean	1,467,934	3.513	402	9.7E-04
		(± SD)	1,246,226	(3.162)	328	(8.5E-04)
	Meso	Mean	106,995	0.258	351	8.2E-04
		(± SD)	89,341	(0.231)	315	(6.8E-04)
	Macro	Mean	19,446	0.046	751	1.6E-03
		(± SD)	29,703	(0.064)	1,864	(3.9E-03)
September 2018 (Fr)	Mean		3,214,526	14.175	2,516	1.1E-02
	(± SD)		7,664,099	(33.873)	5,664	(2.5E-02)
	Median		208,059	0.874	213	1.1E-03
	Min		112,319	0.588	77	3.6E-04
	Max		20,580,976	90.933	15,329	6.8E-02
	Micro	Mean	1,239,399	3.097	1,061	2.6E-03
		(± SD)	2,073,484	(5.024)	2,208	(5.4E-03)
	Meso	Mean	210,804	0.521	1,186	2.9E-03
		(± SD)	442,420	(1.072)	2,579	(6.3E-03)
	Macro	Mean	54,507	0.133	2,268	5.5E-03
		(± SD)	130,500	(0.316)	5,563	(1.4E-02)
June 2019 (Fr)	Mean		417,339	1.032	644	1.4E-03
	(± SD)		388,632	(0.845)	901	(1.9E-03)
	Median		333,161	0.771	179	5.2E-04
	Min		103,194	0.298	3	9.9E-06
	Max		1,167,266	2.483	2,436	5.2E-03
	Micro	Mean	514,353	0.900	0	1.8E-04
		(± SD)	374,800	(0.677)	0	(2.2E-04)
	Meso	Mean	60,223	0.120	0	5.8E-04
		(± SD)	83,425	(0.163)	0	(6.8E-04)
	Macro	Mean	5,733	0.012	0	6.7E-04
		(± SD)	6,701	(0.014)	0	(1.2E-03)

July 2019 (Fr)	Mean		268,379	0.914	127	3.7E-04
	(± SD)		80,438	(0.407)	192	(5.3E-04)
	Median		256,282	0.824	45	1.5E-04
	Min		179,175	0.534	7	2.2E-05
	Max		362,067	1.734	538	1.5E-03
	Micro	Mean	335,439	0.833	25	5.8E-05
		(± SD)	105,916	(0.403)	13	(2.7E-05)
	Meso	Mean	29,500	0.064	39	8.2E-05
		(± SD)	25,933	(0.040)	48	(8.8E-05)
	Macro	Mean	8,238	0.017	117	2.3E-04
		(± SD)	9,675	(0.018)	226	(4.4E-04)
August 2019 (Fr)	Mean		1,019,477	3.715	695	2.6E-03
	(± SD)		629,026	(2.507)	1,135	(4.8E-03)
	Median		825,723	3.458	222	8.8E-04
	Min		430,167	1.097	27	1.6E-04
	Max		2,132,806	8.827	3,236	1.3E-02
	Micro	Mean	954,326	3.428	163	5.5E-04
		(± SD)	563,873	(2.235)	137	(5.0E-04)
	Meso	Mean	71,263	0.248	161	5.8E-04
		(± SD)	61,644	(0.248)	204	(8.5E-04)
	Macro	Mean	11,144	0.039	377	1.5E-03
		(± SD)	11,289	(0.047)	842	(3.5E-03)
September 2019 (Fr)	Mean		3,824,222	10.171	3,487	9.1E-03
	(± SD)		8,703,643	(22.211)	8,598	(2.2E-02)
	Median		564,623	1.675	283	9.7E-04
	Min		325,820	1.195	64	2.4E-04
	Max		23,560,179	60.530	22,982	5.9E-02
	Micro	Mean	4,595,375	9.515	2,411	4.9E-03
		(± SD)	10,265,728	(20.732)	6,177	(1.3E-02)
	Meso	Mean	302,166	0.622	1,814	3.7E-03
		(± SD)	711,757	(1.439)	4,559	(9.2E-03)
	Macro	Mean	15,411	0.033	231	5.0E-04
		(± SD)	20,681	(0.041)	271	(5.7E-04)
May 2020 (Fr)	Mean		461,548	NA	2,240	NA
	(± SD)		689,288	NA	3,993	NA
	Median		255,084	NA	30	NA
	Min		88,038	NA	4	NA
	Max		2,013,883	NA	9,983	NA
	Micro	Mean	1,200,730	NA	1,707	NA
		(± SD)	1,841,745	NA	3,841	NA
	Meso	Mean	56,363	NA	1,766	NA
		(± SD)	131,685	NA	3,954	NA
	Macro	Mean	6,371	NA	2,589	NA
		(± SD)	12,653	NA	4,510	NA
June 2020 (Fr)	Mean		226,302	3.680	163	2.7E-03
	(± SD)		180,572	(3.424)	184	(4.1E-03)
	Median		151,051	2.293	64	1.1E-03
	Min		97,741	0.203	42	6.8E-05
	Max		595,702	8.927	449	1.1E-02
	Micro	Mean	377,693	1.948	146	6.9E-04
		(± SD)	295,671	(0.560)	147	(5.5E-05)
	Meso	Mean	21,112	0.069	134	2.3E-04
		(± SD)	22,455	(0.011)	201	(2.1E-04)
	Macro	Mean	2,167	0.011	10	1.2E-04
		(± SD)	2,116	(0.011)	12	(1.7E-04)

July 2020 (Fr)	Mean		254,053	0.468	121	2.4E-04
	(± SD)		160,485	(0.692)	82	(4.0E-04)
	Median		231,550	0.147	145	7.6E-05
	Min		111,664	0.056	13	1.6E-05
	Max		530,492	1.932	237	1.1E-03
	Micro	Mean	302,077	0.896	61	2.2E-04
		(± SD)	185,171	(0.855)	45	(2.7E-04)
	Meso	Mean	15,573	0.045	33	6.7E-05
		(± SD)	11,704	(0.041)	23	(6.1E-05)
	Macro	Mean	3,530	0.010	59	1.8E-04
		(± SD)	2,283	(0.010)	57	(2.6E-04)
August 2020 (Fr)	Mean		3,327,647	5.101	7,960	1.1E-02
	(± SD)		6,698,907	(8.606)	18,589	(2.4E-02)
	Median		556,803	1.457	395	5.1E-04
	Min		86,888	0.277	36	3.2E-04
	Max		18,369,193	23.854	50,012	6.5E-02
	Micro	Mean	3,590,185	6.144	1,576	2.7E-03
		(± SD)	7,267,989	(9.227)	3,065	(4.0E-03)
	Meso	Mean	290,960	0.491	1,391	2.3E-03
		(± SD)	591,696	(0.755)	2,793	(3.6E-03)
	Macro	Mean	16,214	0.029	6,368	1.0E-02
		(± SD)	17,920	(0.029)	16,069	(2.1E-02)
September 2020 (Fr)	Mean		259,344	0.806	304	9.6E-04
	(± SD)		123,155	(0.282)	412	(1.1E-03)
	Median		299,170	0.904	162	5.1E-04
	Min		82,753	0.340	10	1.8E-04
	Max		405,544	1.083	1,207	3.2E-03
	Micro	Mean	274,805	0.742	103	2.9E-04
		(± SD)	128,646	(0.254)	70	(1.4E-04)
	Meso	Mean	19,730	0.054	210	5.7E-04
		(± SD)	18,009	(0.041)	392	(9.6E-04)
	Macro	Mean	3,123	0.009	37	1.0E-04
		(± SD)	2,802	(0.006)	43	(1.0E-04)
Spanish waters	Mean		255,601	1.610	312	1.4E-03
	(± SD)		347,919	(2.603)	934	(4.0E-03)
	Median		169,453	0.894	40	1.8E-04
	Min		33,614	0.103	1	0.0E+00
	Max		2,526,181	19.074	7,047	2.8E-02
French waters	Mean		1,213,110	3.978	1,663	4.4E-03
	(± SD)		3,624,181	(11.758)	5,957	(1.3E-02)
	Median		327,290	1.195	191	8.1E-04
	Min		54,244	0.056	3	9.9E-06
	Max		23,560,179	90.933	50,012	6.8E-02
TOTAL (2017-2020)	Mean		739,395	2.748	998	2.9E-03
	(± SD)		2,625,271	(8.424)	4,338	(9.5E-03)
	Median		232,227	0.982	74	3.9E-04
	Min		33,614	0.056	0.7	0.0E+00
	Max		23,560,179	90.933	50,012	6.8E-02

Supplementary Table 5.7

Supplementary Table 5.7. Plastic abundance results (mean ± standard deviation 'SD') by station. Stations from 1-33 refer to Spanish coastal waters, and 34-40 to French coastal waters. Data from 2017-2020 survey. Observed data, no corrections have been applied to the abundance and densities.

Station	**Latitude**	**Longitude**	**items/km^2** (mean ± SD)	**g(dw)/km^2** (mean ± SD)	**items/m^3** (mean ± SD)	**g(dw)/m^3** (mean ± SD)
1	43.4271167	-1.6345	4,121,843 ± 8,026,774	5134 ± 7523	9.804 ± 18.324	1.1E-02 ± 1.7E-02
2	43.44435	-1.6148667	436,919 ± 354,050	297 ± 322	1.288 ± 1.241	6.8E-04 ± 5.1E-04
3	43.4945833	-1.5614667	1,875,991 ± 4,967,210	4394 ± 13724	3.132 ± 5.552	6.4E-03 ± 1.6E-02
4	43.48855	-1.6109167	424,643 ± 414,655	428 ± 785	1.077 ± 1.190	1.0E-03 ± 1.7E-03
5	43.43065	-1.6864667	613,077 ± 736,577	437 ± 569	1.440 ± 1.663	1.0E-03 ± 1.3E-03
6	43.42425	-1.7268	564,918 ± 763,773	209 ± 333	1.820 ± 2.537	6.5E-04 ± 1.1E-03
7	43.39685	-1.72175	772,973 ± 1,047,841	1312 ± 2242	2.445 ± 3.002	2.8E-03 ± 5.2E-03
8	43.350772	-2.3763994	102,645 ± 51,539	43 ± 37	0.313 ± 0.108	1.1E-04 ± 9.2E-05
9	43.3879643	-2.3760183	144,518 ± 83,660	463 ± 370	0.601 ± 0.554	1.4E-03 ± 1.1E-03
10	43.4259312	-2.3756284	235,373 ± 139,467	228 ± 328	0.496 ± 0.213	4.4E-04 ± 6.2E-04
11	43.3412154	-2.3532666	93,056 ± 58,678	29 ± 39	0.302 ± 0.166	8.4E-05 ± 1.1E-04
12	43.3795169	-2.3528596	153,949 ± 74,749	17 ± 20	0.392 ± 0.075	4.4E-05 ± 5.1E-05
13	43.4166422	-2.3524644	148,951 ± 10,318	37 ± 37	0.446 ± 0.080	1.1E-04 ± 1.1E-04
14	43.3320746	-2.3073956	126,357 ± 41,345	47 ± 47	0.407 ± 0.230	1.5E-04 ± 1.6E-04
15	43.3661115	-2.3070085	193,998 ± 41,280	43 ± 25	0.493 ± 0.053	1.0E-04 ± 4.0E-05
16	43.4044541	-2.3065716	192,482 ± 100,380	395 ± 486	0.508 ± 0.194	9.7E-04 ± 1.2E-03
17	43.342356	-2.2455338	966,439 ± 1,351,840	483 ± 798	2.104 ± 2.722	1.0E-03 ± 1.7E-03
18	43.3769089	-2.2451056	165,240 ± 68,603	110 ± 160	0.439 ± 0.165	2.7E-04 ± 3.9E-04
19	43.4106678	-2.2446864	155,438 ± 104,842	478 ± 791	0.374 ± 0.207	1.1E-03 ± 1.7E-03
20	43.3405906	-2.2009373	159,150 ± 102,787	80 ± 99	0.584 ± 0.328	3.0E-04 ± 3.3E-04
21	43.3750588	-2.2004848	206,058 ± 91,456	37 ± 56	0.649 ± 0.099	1.0E-04 ± 1.4E-04
22	43.4091423	-2.2000367	251,011 ± 233,152	53 ± 42	0.688 ± 0.625	1.4E-04 ± 1.1E-04
23	43.3318862	-2.1311077	284,542 ± 232,901	2476 ± 3959	0.921 ± 0.754	6.1E-03 ± 9.4E-03
24	43.3680165	-2.1305921	161,615 ± 152,478	72 ± 118	0.470 ± 0.340	1.8E-04 ± 2.9E-04
25	43.4039183	-2.1300789	769,069 ± 1,127,279	1391 ± 2377	2.293 ± 3.277	4.1E-03 ± 7.0E-03
26	43.3490672	-2.064713	157,359 ± 114,152	14 ± 12	0.368 ± 0.243	3.1E-05 ± 2.0E-05
27	43.3852472	-2.0641569	151,045 ± 101,115	83 ± 87	0.422 ± 0.347	2.1E-04 ± 1.9E-04
28	43.4198766	-2.0637827	210,346 ± 148,457	20 ± 23	0.815 ± 0.624	7.5E-05 ± 9.6E-05
29	43.3697125	-1.9806715	446,571 ± 298,703	42 ± 32	1.538 ± 1.724	8.7E-05 ± 5.5E-05
30	43.4039525	-1.9800975	277,733 ± 106,408	50 ± 75	0.800 ± 0.152	8.9E-05 ± 1.1E-04
31	43.438631	-1.9795152	287,998 ± 190,676	984 ± 1703	0.889 ± 0.461	2.8E-03 ± 4.8E-03
32	43.3713676	-1.9287175	370,106 ±325,886	121 ± 97	0.858 ± 0.500	2.9E-04 ± 1.6E-04
33	43.4204859	-1.9278518	213,269 ± 39,141	212 ± 198	0.970 ± 0.289	1.0E-03 ± 1.1E-03
34	43.462323	-1.9271127	206,530 ± 53,821	138 ± 176	0.774 ± 0.019	4.4E-04 ± 4.4E-04
35	43.4078261	-1.8741572	328,216 ± 374,698	306 ± 386	0.829 ± 0.812	7.3E-04 ± 8.4E-04
36	43.4439888	-1.8734867	540,117 ± 716,303	1197 ± 1636	0.904 ± 1.124	2.0E-03 ± 2.6E-03
37	43.4796588	-1.8728241	91,988 ± 27,481	19 ± 5	0.229 ± 0.040	4.9E-05 ± 1.8E-05
38	43.4268859	-1.7878679	311,616 ± 206,730	180 ± 259	0.736 ± 0.466	4.2E-04 ± 6.0E-04
39	43.4602377	-1.7872018	165,705 ± 60,324	347 ± 548	0.434 ± 0.187	1.0E-03 ± 1.6E-03

CHAPTER 3

Publication data

Type	Original research article
Title	Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter
Authors	Irene Ruiz1*, Oihane C. Basurko1, Anna Rubio1, Matthias Delpey2, Igor Granado1, Amandine Declerck2, Julien Mader1 and Andrés Cózar3
Affiliation	1AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Pasaia, Spain 2 Rivages Pro Tech, SUEZ Eau France, Bidart, France 3Departamento de Biología, University of Cadiz and European University of the Seas (SEA-EU), Instituto Universitario de Investigación Marina (INMAR), Puerto Real, Spain
Journal	Frontiers in Marine Science
Year	2020
Volume	7
Stage of publication	Published

ABSTRACT

Large scale convergence regions of floating marine litter are commonly observed in semi-enclosed seas as the Bay of Biscay. However, clean-up activities on such accumulation regions are limited by the spread of the large-size floating litter on the sea surface. Data gathered by a small-scale fishing vessel devoted to active fishing for floating litter activities during the spring and summer of 2018 reveals that the linear streaks of high concentration of floating litter (so-called litter “windrows”) are common accumulation structures in the south-east coast of the Bay of Biscay. The random search of litter windrows for their collection through surface tows of macro-nets was proved to be an effective action for floating litter mitigation. A total of 196 tows collected 16.2 tons of floating marine litter in 68 working days. Most of the litter windrows were around 1 km length and, on average, accumulated 77.75 kg of floating marine litter. Fishing, shipping and aquaculture sectors were the source of 35% of the 4,130 litter items analyzed (55% in weight of the sourced items), and plastic was the most common type of material (96% in terms of items). A better understanding of the phenomenon of the litter windrows, capable to guide clean-up efforts in space and time, would provide a considerable improvement in the efficiency of mitigation actions to reduce the marine litter pollution. The observations of litter windrows in the coastal area of the south-east of the Bay of Biscay demonstrate the key role of submesoscale processes in the distribution of FML. The present work provides a thorough description of floating litter windrows in nature, which it was nonexistent to date. The results are the kind of proof necessary to boost the research addressed on the submesoscale aggregations of FML. Coupling litter windrows observations with remote-sensing technology and high-resolution modelling techniques offer great opportunities for the mitigation actions against marine litter.

KEY WORDS

Floating marine litte; litter windrows; Bay of Biscay; active fishing for litter; coastal integrated management; LIFE LEMA

INTRODUCTION

About half of the floating marine litter (FML) in the world is thought to be confined in great accumulation zones or hot spots (UNEP, 2016). Much attention has been paid to understand the global convergence zones associated to the subtropical gyres (Law et al., 2010;Eriksen et al., 2013;Cózar et al., 2014;Lebreton et al., 2018). Nevertheless, global models also consistently predict litter accumulation zones in semi-enclosed seas as the Bay of Biscay, where the concentration of FML is higher in comparison to other European regions (Lebreton et al., 2012;van Sebille et al., 2012). Besides, regional models point to the importance of FML accumulation zones in the coastal waters of the south east Bay of Biscay (SE Bay of Biscay) caused by the combination of relatively long residence times ant the litter influx from both local and remote areas (Pereiro et al., 2018). Moreover, the predicted FML accumulations in this area seem to be significantly modulated at seasonal scale. During spring and summer, the more variable and weaker currents result in high particle retention, while the northward evacuation of particles along the French coast are favored during autumn and winter by the typical surface current regime (Declerck et al., 2019).

At smaller spatio-temporal scales (< 10 km or < 1 month), the accumulation of FML near the coastal areas show high variability in response to the combined effect of different small-scale processes such as surface wave interactions with current and mixing, Langmuir circulation and (sub) mesoscale eddies. These events lead to create a heterogeneous and patchy litter field on the surface of the ocean (UNEP, 2016;van Sebille et al., 2020). However, most of the existing operational coastal models are configured with spatio-temporal scales not suited to capture this small-scale variability, which is key to monitor and predict the FML distribution in coastal areas, as it happens in the case of the SE Bay of Biscay. Likewise, field investigations conducted so far to assess its abundance and the distribution have been limited to visual ship transects surveys with reduced spatial resolution (Boyra et al., 2013).

The magnitude of the impacts derived from FML in the European waters has been highlighted by the European Marine Strategy Framework Directive (MSFD) (EC., 2008) which invited member states to promote a cross-border and transnational cooperation on this issue to adopt strategies to combat marine litter. However, international efforts to collect FML in the globally predicted convergence zones have been limited. One of the difficulties in setting targets and mitigation plans for FML is the lack of field data and methodologies for ensuring their effectiveness.

In the SE Bay of Biscay, at the Atlantic border between France and Spain, local authorities have funded active fishing for FML activities (“active retrieval of marine litter by vessels that have been paid to perform this activity” (UNEP(DEPI)/MED, 2016)) in the French coastal area since 2003. This action, closely aligned with the European policy requirements, responds to the growing amount of litter affecting the local beaches. FML accumulated in the convergence areas close to the coast is likely to end washed up on beaches, with the consequent environmental and socio-economic impact for a very touristic region like the SE Bay of Biscay.

The above-mentioned active collection of FML is carried out by an artisanal fishing vessel, Itsas Belarra, based in Saint Jean de Luz port (Pyrénées-Atlantiques, France) and chartered by the Syndicat Mixte Kosta Garbia, an association gathering local public authorities committed to the fight against FML. The Itsas Belarra combines the collection of FML (from May until September) with the fishing of seaweed for commercial purposes, the latter taking place during fall and winter. After more than a decade of operation, the collection of FML has gained in efficiency since the efforts are concentrated along linear streaks with high concentration of litter. called litter “windrows” (Frontiers in Marine Science, 2020). Although there are some references to these small-scale convergence features in the literature, little is known regarding the way litter is accumulated in such areas, their residence times, and the physical drivers forming such structures. Since a better understanding of this processes could have a direct impact in the optimization of FML collection, the activity of the Itsas Belarra was protocolized and monitored during several months in the framework of the EU co-funded LIFE LEMA project. Moreover, active fishing for litter can provide initial estimates of FML distribution patterns, type and sources. This latter aspect is also key since sources of marine litter are diverse and ocean dynamics turn it into a transboundary issue requiring collective action (OSPAR, 2014).

Within this context, with the aim of improving the integrated monitoring of the coastal waters of the SE Bay of of Biscay in the framework of JERICO-S3 project, this contribution aims at assessing the litter windrows' features in the area through a scientifically assessed active fishing for litter activity. The data obtained provides, for the first time, estimates of loading, composition, frequency and size of the litter windrows as well as experience for its collection. The analysis is aimed to improve forthcoming fishing for litter collection activities across the region with possible application to other coastal areas under similar forcings and pressures.

MATERIAL AND METHODS

Sampling of litter windrows

The data used in this contribution relates to the Itsas Belarra's active fishing for litter activity, mainly oriented to FML collection in litter windrows within the south-west French coastal area during spring and summer 2018 (Fig 5.9). Litter windrows were detected by the crew by visual observations and net tows were carried out along the litter windrow following the streak of higher FML concentrations (Fig 5.10). The fishing gear employed for the collection consisted of an artisanal net adapted for FML collection, featuring a rectangular metallic frame and a nylon net with a 20 mm mesh size. Thus, clean-ups were focused on the so-called macro litter (>2 cm), which is the most easily retrievable form of litter pollution. The net 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. The duration per tow varied between 3 - 60 minutes depending on the amount of FML collected. The net was monitored by the crew during each trawl to avoid an overload of the net and to simplify its post-handling. Litter windrows also accumulated natural wooden fragments and seaweed. However, large wooden fragments were avoided by using brailers in order to prevent damaging the net. Although some of these large natural items were collected by hand and stored onboard for navigation safety purposes, they were not systematically sampled. A dedicated energy monitoring device, named SIMUL (developed by AZTI, Gabiña and Basurko, 2018) was installed onboard to provide position coordinates, time and speed of the vessel, with a 0.1 Hz frequency. This information was completed by the location and time data from the Marine Navigation Software MaxSea, available onboard. Moreover, information regarding initial position and initial time of each tow was manually recorded by the crew in a spreadsheet. Once the tow finished, FML was stored in a coded big bag, which was subsequently weighted onboard with a load cell. Finally, the different information recorded about each tow was reported daily by the crew through a dedicated web interface implemented as part of the LIFE LEMA project.

Processing of tow data

A detailed analysis on the track record was carried out based on the speed range of the vessels. It was considered that at vessel speeds ≤ 3 knots the vessel was involved in towing the net; in contrast, at speeds > 3 knots the vessel was sailing to new locations, searching for litter, or going/coming back from the port. Thanks to the analysis: (1) the initial location of the tow was verified, and (2) the final position identified. The cases in which no data from SIMUL device was available, speed was calculated directly by the division of distance and time values covered between consecutive positions of the vessel provided by the MaxSea software. During the weighting of the catch, the litter was wet. A 2.47 wet/dry FML litter ratio was applied to Itsas Belarra weight values, based on lab tests with the collected litter.

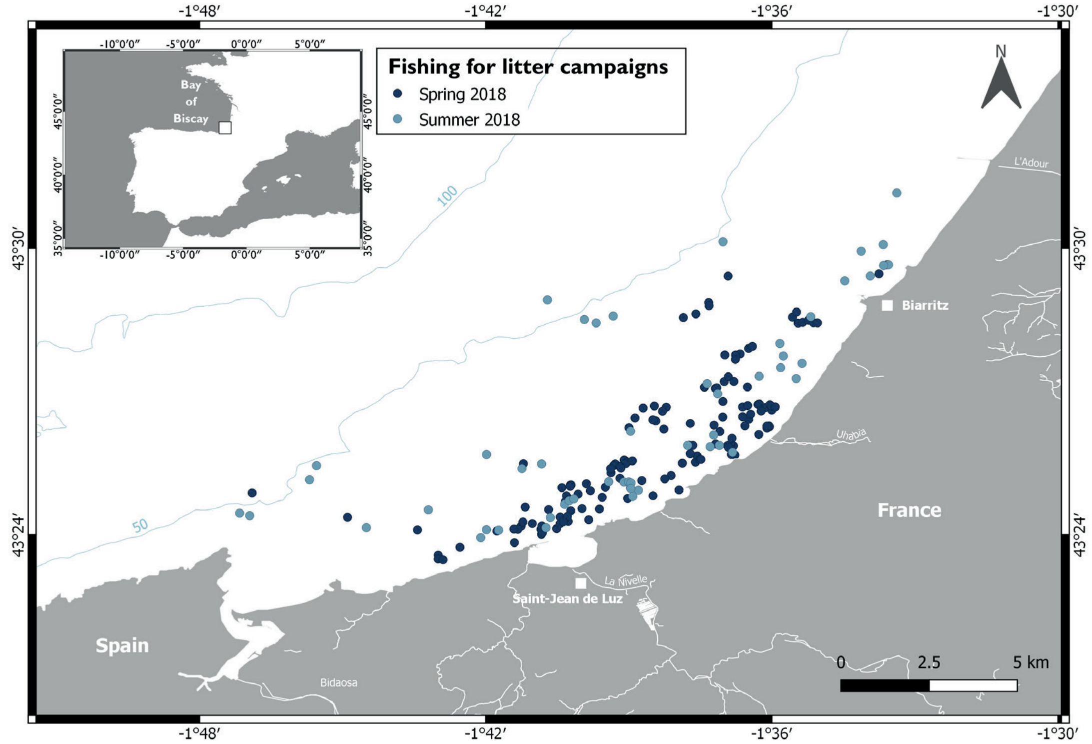


Fig 5.9. Location of the study area. Circles show the initial positions of the tows.

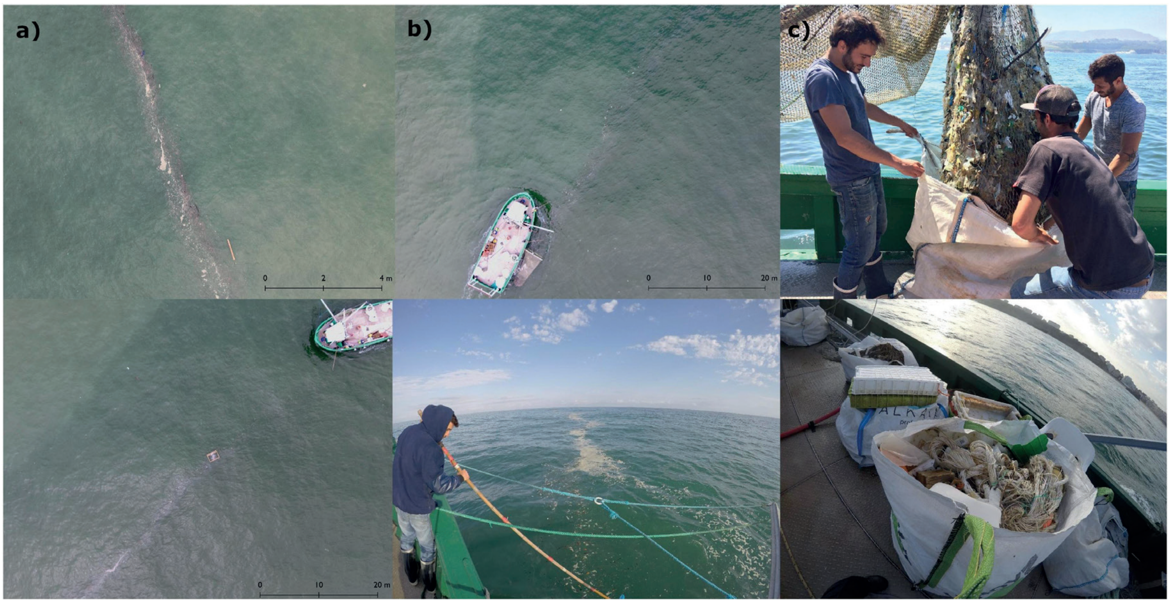


Fig 5.10. FML collection throughout the litter windrow (a) Airborne pictures of litter windrow collected by a drone survey, (b) Vessel operating during collection, (c) Unloading of FML and storage on board. Written informed consent was obtained from the Itsas Belarra crew for the publication of any potentially identifiable images or data included in this article.

Distribution analysis

A total of 68 fishing days and 166 tows seasonally distributed were selected and analyzed in detail (Supplementary Fig 5.2-5.8). The results are based on the assumption that every tow corresponds to a litter windrow; in contrast, for the cases that the vessel follow a very chaotic path , it was assumed that the litter accumulated in patches, so 30 tows were discarded. The study area was discretized into a 0.5 km x 0.5 km grid cell. The weight of the FML retrieved in every tow was divided equally into the number of positions recorded along the tow, and the resulting weight values were assigned to the corresponding position and plotted in the map. The accumulated distribution of weight values per cell for the whole campaign was calculated by adding every weight value inside the same cell. Weight data were displayed separately by season to assess its influence for spring 2018 and summer 2018. Histograms of the weight and length of the litter windrows were plotted. A first exploration of the environmental conditions leading to windrows formation was performed through the analysis of prevailing wind direction, wind speed, and number of litter windrow observed for spring and summer 2018.To that end, a weighted average of wind speed and the mode of the prevailing wind directions were calculated for the 48 hours previous to the observation dates, based on the hourly wind data provided by Bilbao-Vizcaya buoy (Measuring Networks and Forecasting Systems of Puertos del Estado, http://www.puertos.es/).

Characterization by composition and source

A total of 11 samples were randomly collected from the big bags for their further analysis in lab, with the aim of characterizing the marine litter collected in the windrows and defining its potential sources. Almost 240 kg of the litter items collected were sorted out according to the Master list included in the “Guidance on Monitoring of Marine Litter in European Seas” (Galgani et al., 2013). As a result, the items > 2.5 cm were sorted in 7 main categories based on their material (artificial polymer materials, rubber, cloth/textile, wood/processed wood, paper/cardboard, metal, and glass/ceramic) and 68 sub-categories based on their typology. The list was regularly updated during the analysis process to incorporate new item sub-categories that were omitted in the Guidance but were present in the waters of the SE Bay of Biscay (Supplementary Table 5.8). Items were also weighed by group of sub-categories using an electronic balance with a precision of ± 0.01 g. The ten most common items in number and in weight were also identified. Non-anthropogenic items collected by the nets were omitted in this study. The items < 2.5 cm were classified as microplastics.

In line with the most common categorization of marine litter origins, items were allocated to land – based sources and sea – based sources categories. One more specific category, non-sourced, was added to classify the litter items that could not be directly connected to either of the two groups. Based on the OSPAR indicator-items methodology (Veiga et al., 2016), a subsequently division was defined by distinguishing fishing and shipping activities for sea–based sources and Tourism and Recreational activities and Sanitary and sewage-related waste for land–based sources. Sources, expressed as a percentage contribution of each category, were also analyzed by type of material to explore their relationship with the litter composition. In total, 4,130 litter items were classified and weighted.

RESULTS

Litter windrows features

During spring and summer 2018, the Itsas Belarra collected 14 tons of FML by towing the net in 166 litter windrows. The number of litter windrows was, by far, higher during spring (74.10%, 123 litter windrows) than summer 2018 (25.90%, 43 litter windrows). This difference between seasons (Fig 5.11) was also observed regarding the weight of FML collected per windrow. As an average, the litter windrows included 91.74 ± 53.137 kg of FML during spring and 62.96 ± 39.63 kg during summer (min-max: 10-195 kg), which revealed less loaded windrows during the summer. In contrast, the mean length of the litter windrows was quite similar in both seasons (1.01 – 1.47 km); nonetheless, longer litter windrows (> 3 km) were more frequent in summer (11%) than in spring (0.7%).

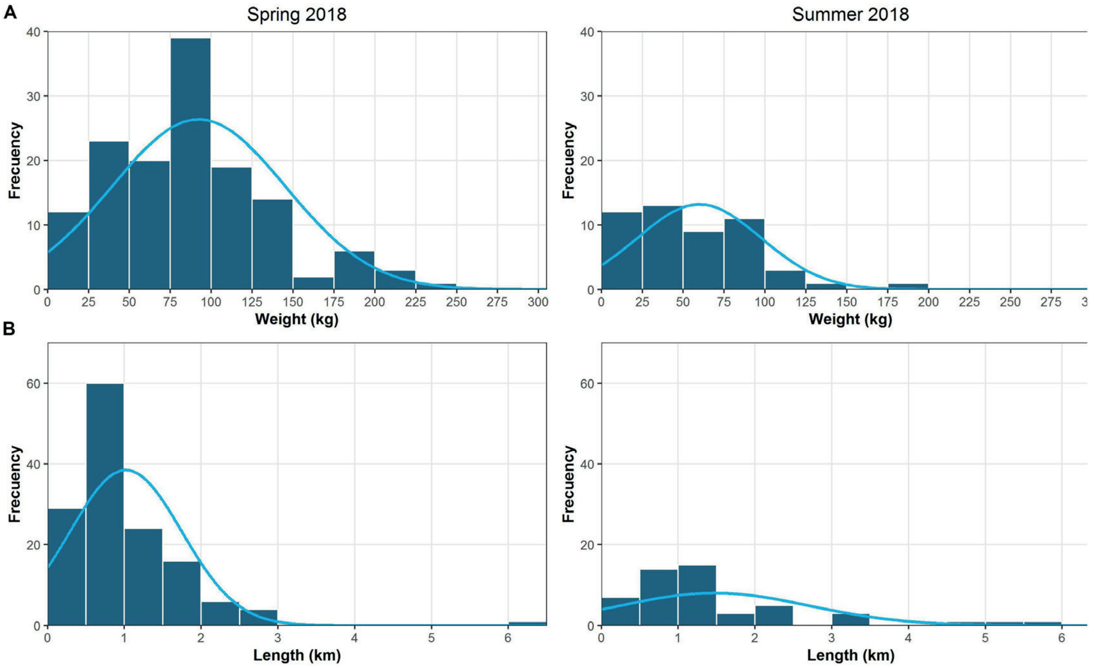


Fig 5.11. Distribution of FML wet weight (A) and length (B) of litter windrows during spring (left plot) and summer 2018 (right plot).

Spatial distribution

Significant accumulation areas were located within the first nautical mile from the coastline, mainly during spring 2018 (Fig 5.12 and Supplementary Fig 5.9-5.10). The highest loads per windrow (> 300 kg) were also collected during this season. During summer 2018, a considerably lower amount of FML was observed comparing to spring. During this period, litter was unevenly spatially distributed. However, similar abundance values among the cells (1-50 kg) indicates the lack of heavy accumulation areas. Few isolated cells included presence of litter in both seasons, most of them coinciding also to low weight values (1-50 kg). The analyses on wind conditions showed that the litter windrows were mainly linked to low intensity westerly and easterly winds (0 - 4 m/s) in spring and to southerly winds in summer(Fig 5.13).

Composition and sources

Plastic, found in the 100 % of the samples, was the dominating sub-category by number of items and weighing. 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 %. In contrast, in terms of weight, Nets and pieces of net, Other plastic/polystyrene and Floats for fishing nets were the most frequent, representing 48 % of the total litter (Fig 5.14). Items belonging to the rest of the sub-categories were collected occasionally, accounting only the 3.38 % in number. Nevertheless, Glass/Ceramics was the second most abundant sub-category according to weight values, while the less common sub-categories represented the 2.21 % of the litter collected.

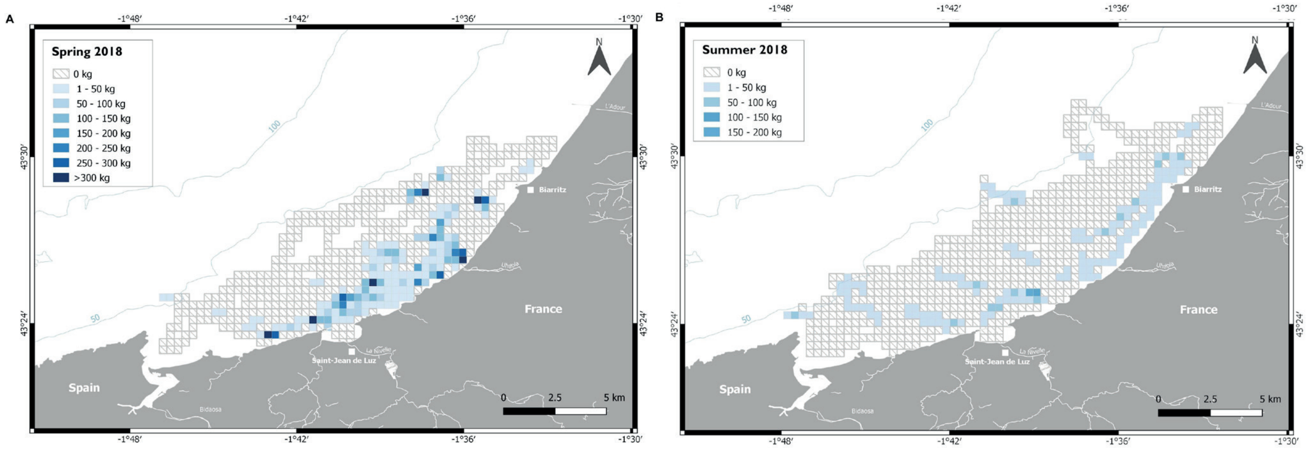


Fig 5.12. Abundance of FML in the litter windrows calculated per cell of 0.5 km × 0.5 km for spring (A) and summer 2018 (B).

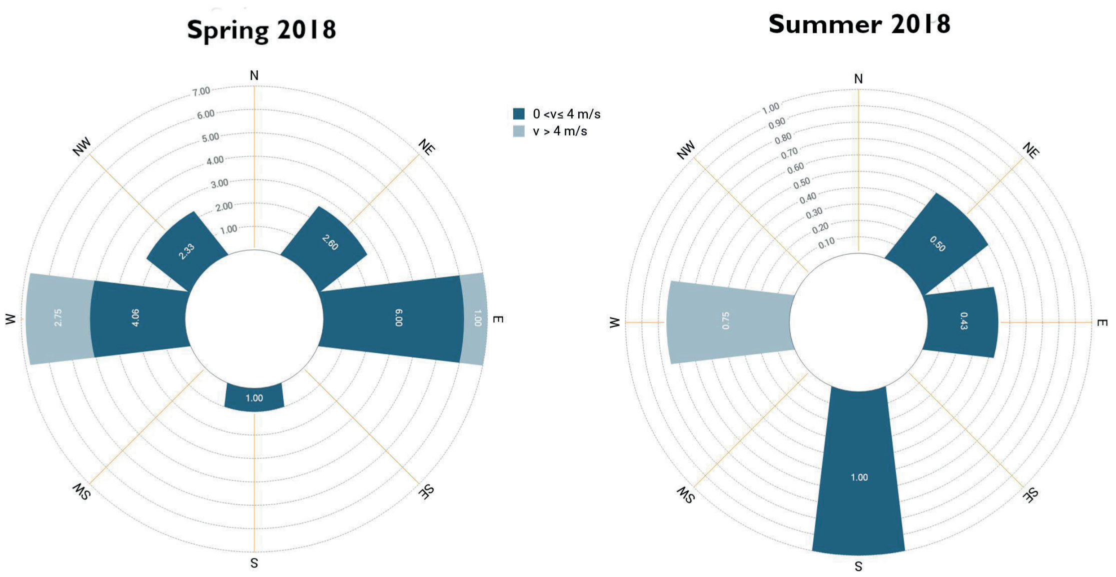


Fig 5.13. Wind direction and intensity during the litter windrow events in spring and summer 2018. Number of litter windrows occurrence during spring and summer 2018 regarding to wind direction and intensity.

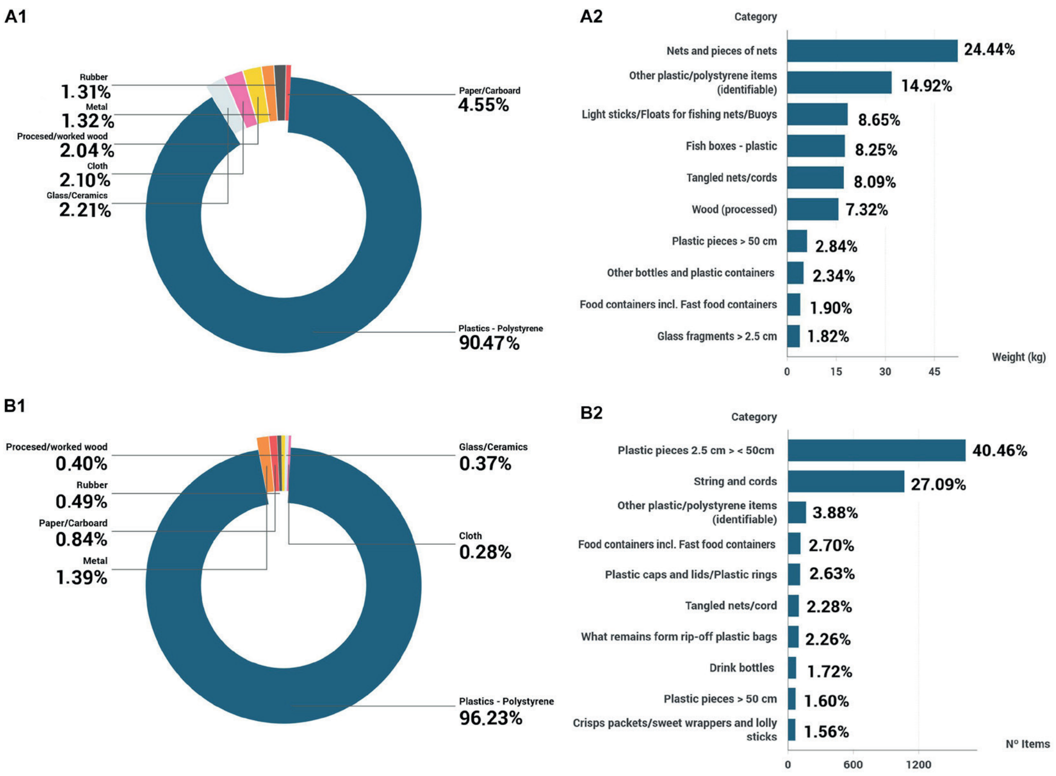


Fig 5.14. Percentage of number (A1) and weight of items (B1) collected by type of material, and Top 10 of 554 items collected by weight (A2) and by number (B2).0.5 km for spring (A) and summer 2018 (B).

The rest of the top-ranking varied widely according number and weighing values though tangled nets/cords and single use items as Food containers or Drink bottles were also frequently recorded.

Regarding the origin of the collected marine litter, it must be noted that it was not possible to assign a large amount of items to neither sea nor land-based origin because they were unidentifiable fragments or their origin could be both. This Non-sourced items represented over the 43.99 % 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.

Concerning the material which source could be determined (Fig 5.15), 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 %. 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 orgin items. Single-use plastics, entering the ocean from multiple sources and pathways, account for 18.5%.

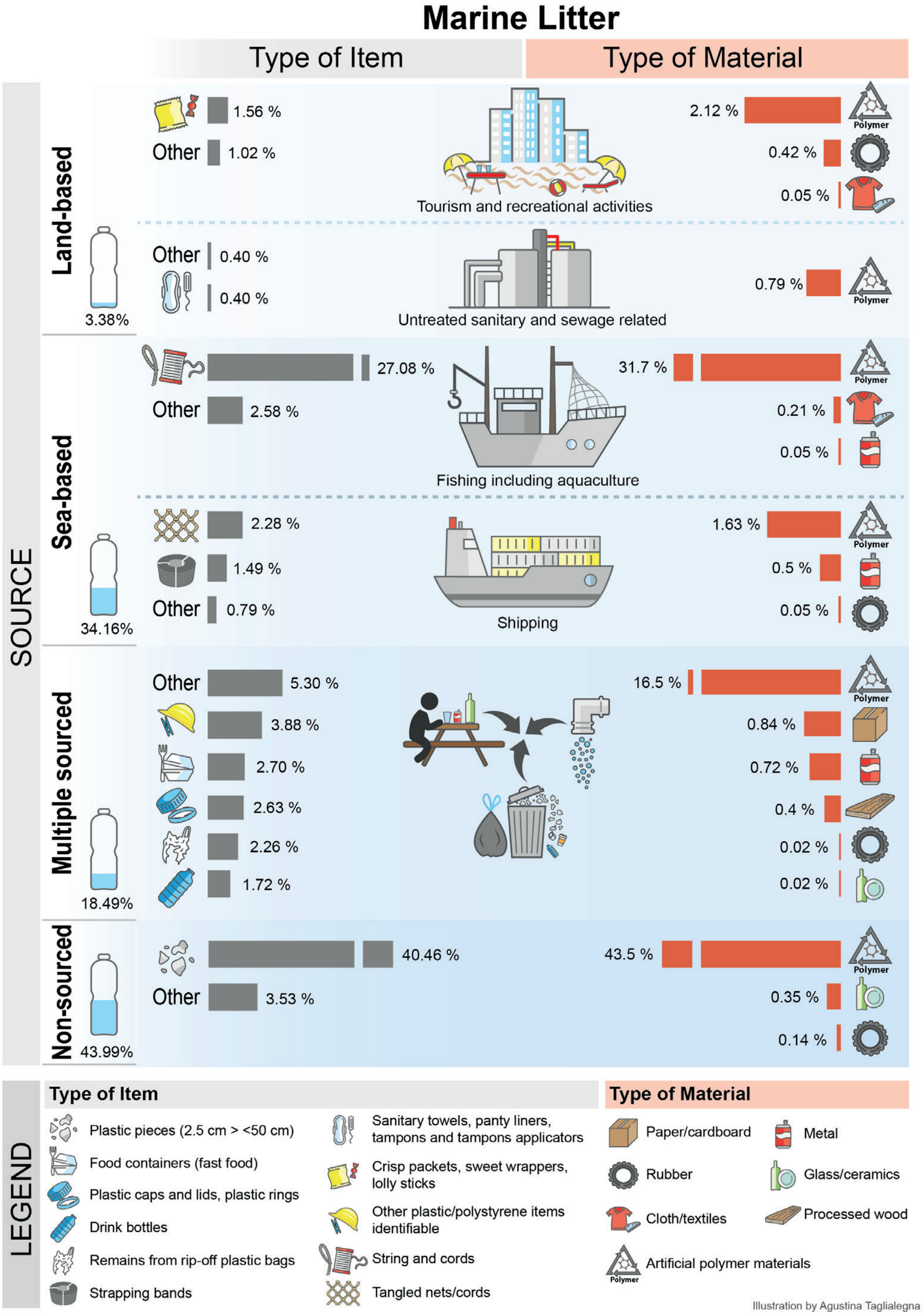


Illustration by Agustina Taglialegna

Fig 5.15. Percentage of litter items collected per source and related to type of material.

DISCUSSION

Litter Windrows in the Coastal Waters of SE Bay of Biscay

Marine litter dispersion and washing-up on shore are strongly influenced by ocean currents, tidal cycles, regional-scale topography (including sea-bed topography) and wind (Jeftic et al., 2009). These, hydrodynamic factors and geomorphological characteristics of the coastline, coupled by riverine inputs and the presence of anthropogenic activities are the main factors modulating the presence of marine litter in the coastal area (Wei et al., 2012;Ramirez-Llodra et al., 2013). However, there are large variations on their concentration at small scales due to the complexity of local coastal dynamics and interactions with the wind (Law et al., 2014). The results obtained by our study in the SE Bay of Biscay are a showcase on how small-scale processes can play an important role in shaping the distribution of FML. For the first time, a small-scale characterization of the FML hotspots is provided, demonstrating that rectilinear litter windows are frequent and significant accumulation structures in the coastal waters of the SE Bay of Biscay. Higher loads of litter were found at short distances (1 nm) from nearby the coast rather than at farther locations. Variability in time, with higher litter amounts being collected in spring, matched with findings from numerical modelling in this coastal region (Declerck et al., 2019) which pointed out higher residence times in this period. Significant differences in the number, length and load of FML were found between spring (shorter lengths, higher loads) and summer (longer lengths, lower loads) windrows. Nevertheless, it is important to note that the net capacity can limit the windrows length. In higher loads, net can get full and consecutive tows can be observed. This means that the cleanup of all litter into a single windrow occasionally required more than one net tow.

The research about processes leading to the formation, presence and persistence of litter windrows in the study area is out of the scope of the present paper but the first exploration of the wind conditions suggested there was no evidence found on a statistically significant linear relation between wind intensity and litter windrows occurrence.

In a recent observational study, (Meyerjürgens et al., 2019) show that FML transport in coastal areas is strongly influenced by local small-scale processes like tidal jet currents, interactions with a complex shoreline and fronts generated by riverine freshwater plumes. In the study area, litter windrows generation could also relate to the Adour river plume. This river shows a mean annual discharge about 300 m3 s-1 (Morichon et al., 2008), with peak flows exceeding 1000 m3 s-1 (Laiz et al., 2014) and a summer runoff under 500 m3 s-1 (Declerck et al., 2019). The density fronts associated to the Adour freshwater discharge leads to the formation of small-scale surface convergence zones. Further analysis combining in-situ observations with surface current observations, surface drifters and numerical models are needed to better understand its origin and functioning. How the windrows form and evolve in coastal areas appears to be key to improve the efficiency of the FML collection, particularly in nearshore waters, where accessibility and operating costs are smaller than those in offshore waters. Coupling litter windrows observations with remote-sensing and high-resolution modelling provide significant opportunities to advance up the identification of periods and zones of FML accumulation.However, from our experience, it should be noticed that the use of such images to support FML removal operations raises significant challenges. Indeed, high-quality satellite images may be rarely available on a specific targeted date such as previously to a field campaign. Daily images could be available but are rather costly. Free satellite images (e.g. Sentinel-2) are available but on weekly or bi-weekly basis, which is too long compared to the coastal dynamics. Finally, even when available, cloudiness is a hindrance in the high rainfall study region, which limits the possible exploitation of optical images Sources of litter in the coastal waters of SE Bay of Biscay.

Sources of litter in the coastal waters of SE Bay of Biscay

Marine litter windrows in the study area were mainly composed by plastic (96% in terms of items; 76.40% in weight), in agreement with worldwide ranges reported (UNEP and GRID-Arendal, 2016). The Bay of Biscay is an internationally important region for fishing, aquaculture and shipping, (Borja et al., 2019) and our results point at these sea-based activities as the main source of FML (35% of the litter by number and 55% by weight). In the North-East Atlantic and other European Seas, the contribution of land-based sources is prevalent (Reker et al., 2015). The abundance of litter related to fishing activities (mainly floats/buoys) increase in the open ocean, and becomes predominant in weight (Eriksen et al., 2014).

EU is playing a leading role in tackling abandoned, lost or otherwise discarded fishing gears, which account for 27% of total litter stranded on the European beaches (EC., 2019). The new measures addressed on derelict fishing gear by imposing the Extended Producer Responsibility (EPR) should ensure an appropriate management by a dedicated waste and recycling stream for the abandoned, lost or disposed of fishing gears (EC, 2019). At international level, the IMO has strengthened the implementation of MARPOL Annex V (IMO, 2018) recently boosted by the new action plan adopted for ships and vessels including measures like the reporting the loss of fishing gear, facilitating the delivery of retrieved fishing gear to shore facilities.

It is broadly assumed that approximately 80% of marine litter is caused by land-based activities (Faris and Hart, 1995; Allsopp et al., 2006)although further research is needed to verify this gross assumption (Jambeck et al., 2015). The relevance of land-based activities on the FML pollution of the study area was relatively low unlike expected. Land-based sources were related to only by over 3.4% of all the litter items (9% of the identifiable items). Caution was taken when attributing litter items to land-based sources due to the difficulties to point out the origin with clarity except of direct littering related to activities on the coast such beach tourism or sewage-related waste. Certain items, in particular, fragments resulting from the disintegration of larger items, can be very hard or even impossible to identify in terms of their initial purpose and possible origin (Veiga et al., 2016). The data show a considerable degree of uncertainty in litter origins since 43.99% could not be attributed directly to a concrete origin, particularly plastic pieces between 2.5 and 50 cm, which account over the 40.46% in number of the total non-sourced items. Plastic objects exposed to solar UV radiation and oxidation are progressively eroded and fragmented by wind, wave or biological action (UNEP and Grid-Arendal, 2016). The fragmentation rates are relatively high on beaches but generally several orders of magnitude smaller for plastics floating in water (GESAMP, 2015; Efimova et al., 2018). However, very limited information is available on the fragmentation process of plastics in the marine environment (Maes et al., 2019) so both local but also remote origins can be attributed to the analyzed plastic fragmented pieces.

Single-use plastics, entering the ocean from multiple sources and pathways, account for 18.5% by number, lower than expected (but still important) contribution comparing to other studies where single-use plastics are by far the biggest contributor to marine litter (EEA, 2018). The intensive cleaning efforts undertaken during spring and summer in the coastal area, an enhanced appropriate waste management mechanism inland, together with the relevance of the fishing activities in the SE Bay of Biscay might have contributed to reduce the presence of these litter items generated at local scale. Despite the percentages, data on litter in the water column and seafloor would help to understand more precisely the sources of marine litter in the SE Bay of Biscay.

Lessons learned about the floating litter monitoring strategy

Surface-trawling plankton nets are mostly suited to sample small-sized items (few centimeters in size) because of the sparse distribution and frequency of the large items on the ocean surface and the relatively small area sampled by the plankton nets. Visual observations from vessels are able to cover larger sampling areas; however, semi-submerged macro-litter is often overlooked from visual counts (Galgani et al., 2011). Monitoring FML ideally requires large net openings operated at the sea surface, specific ship equipment and significant dedicated ship time, resulting in higher costs and technical difficulties than visual sampling (Galgani et al., 2013). The present study demonstrates that the adaptation of an existing structure of a small-scale fishing vessel combined with the crew expertise allowed for an extensive and cost-effective collection of FML data in the coastal waters of the SE Bay of Biscay. Indeed, Andrés and Basurko (2020) estimated that the cost associated to the active fishing for (floating) litter activities by the Itsas Belarra ranged between 5 and 8 €/kg. Results are proven to be helpful for FML monitoring programs. However, it is important to note that collection is conditioned by the need of FML removal and the willingness to pay for this service by the local authorities (Andrés and Basurko, 2020). Besides, the efficiency of the operations relies on crew experience gathered over previous years collection. In the study area, the collection of occurrence data on litter windrows is centralized in the “LEMA Tool”, a decision-support tool developed during the LIFE LEMA project (http://www.lifelema.eu/) and currently used by local authorities. LEMA Tool is fed by information provided by the skipper in charge of the collection at sea, who after the sighting of a litter windrow reports the coordinates and the collected weight. Moreover, this tool is being strengthened with complementary approaches like videometry or numerical modeling. In return, LEMA Tool provides decision-aid indicators and alerts to make the collection more efficient regarding the different aspects detailed, from the planning of the collection activities to the data analysis and sharing.

Underpinned by our experience, some general guidelines are proposed to enable the replication of the FML collection and management. The acquisition of information, in collaboration with stakeholders, on the occurrence of litter windrows is key for identifying the best period to undertake the FML collection in the target area. Ideally the data-collection plan should cover different seasons and metocean regimes, although its design is contingent upon the needs of the agents funding the collection and the high retention periods (if known). Likewise, the implementation of an adapted protocol on the regular fishing for litter must be agreed with the competent organizations and fishermen to ensure an adequate collection, sampling and disposal of the litter collected. The engagement of the litter-collecting agent to use a standard protocol for litter collection and data reporting on litter windrows is also an important point. This reporting should include at least location of the litter windrows and weight collected per windrow. Data should serve to support numerical modelling approaches and satellite observations. It is expected that these approaches can build support for the fishing for litter in a near future. While the surface trawling to collect litter, it is important to prevent large organic items from entering the net since these items can easily collapse or damage it. The use of additional fishing gears such as brailers or dipnets is recommended for this purpose. In laboratory, the analysis of a dry fraction of the litter, determining the water content in the sample, is also recommended as a way to normalize data. A 2.47 wet/dry FML litter ratio was estimated in the present study. Finally, sharing and disseminating the information about the cleanup activities is vital to further the knowledge about the formation and persistence of litter windrows as well as to strengthen the collaboration between the different actors of the program.

Litter windrows are key to improve the waste management in coastal environments

The presence of litter windrows is pivotal for the efficient collection of litter. The concentration of the marine litter along the windrows is in fact more relevant than the abundance of marine litter itself for the effective active collection at sea. Without the aggregation resulting from of the windrows, the litter would be scattered, and the collection would be much less efficient. The range estimated by Andrés and Basurko (2020) could be further reduced up to 3-8 €/kg, if a guidance tool was employed by the fishers to make the collection much more efficient. But most importantly, the benefits associated to having a clean sea (without marine litter) are superior to the cleaning cost. This statement has been supported by the analyses of McIlgorm et al., (2011) and more recently by King (2018).

A more effective mitigation strategy addressed on the presence of litter windrows at the coastal area requires further background information about spatial distribution, frequency, persistence or origin of these small-scale ocean processes. Data shown here constitutes a first contribution of these characteristics; nonetheless the knowledge resolving litter windrows formation, lifetimes and factors conditioning the litter loads along these convergence lines requires further research.

CONCLUSIONS

Plastic pollution is global mounting problem and it demands similarly ambitious actions. While many pictures and videos in the international media show dense rafts of floating litter on the world oceans, research has overlooked this phenomenon so far. References to litter windrows in the research literature are tangential and limited to a few reports (Ryan et al. 2013; Law et al. 2014). This first descriptive study provides, with unprecedent detail, an observational description of litter windrows in the coastal waters of the SE Bay of Biscay. Litter windrows were usually rectilinear. Longer and less dense windrows may appear in summer. Besides, they often formed further from the coastline during this season.. The common findings of small-scale convergence structures in the coastal waters of the SE Bay of Biscay provide, for the first time, enough evidence to support an active fishing for FML. The lack of previous studies of litter windrows does not enable comparisons with other periods or regions. This experience supports the efficacy of the FML mitigation actions carried by the fishing sector in Bay of Biscay, although preventive measurements should be necessarily conducted at the same time. By collecting FML data according to standardized protocols and by sharing them through international databases, fishing vessels adapted to surface litter collection might significantly underpin the development of targeted and effective actions for preventing FML socio-ecological impacts. In the SE Bay of Biscay, sea-based sources represent a significant contribution to FML generation comparing to land-based sources The top litter subcategories were mainly single use and fishing related items, invoking for measurements to reduce the litter generated by the fishing activities.
In agreement with previous findings on global scale, plastic was the dominant type of material in the SE Bay of Biscay. Litter windrows in Bay of Biscay presented an opportunity to collect floating marine litter in an efficient manner. Furthermore, there remains considerable scope for further improvement of the cleanup effectiveness by increasing our knowledge on the physical processes driving the generation of litter windrows.

AUTHORS CONTRIBUTION

IR sampling characterization, data analysis and writing up. OC experimental design, sampling characterization, intellectual contribution, supervision and validation, review and editing. AR experimental design, intellectual contribution, supervision and validation, review and editing. MD intellectual contribution, review and editing. IG sampling characterization. AD intellectual contribution. JM intellectual contribution. AC intellectual contribution, validation, review and editing.

FUNDING

This research has been partially funded through the EU's LIFE Program (LIFE LEMA project, grant agreement no. LIFE15 ENV/ES/000252. Project coordinator: Diputación Foral de Gipuzkoa/ Gipuzkoako Foru Aldundia,, Spain, France) and EU's H2020 Program (JERICO-S3 project, grant agreement No. 871153. Project coordinator: Ifremer, France).IG has been benefited from a PhD grant from the Department of Economic Development and Infrastructures of the Basque Government. AC received additional support from PLASTREND (BBVA Foundation) and MIDaS (CTM2016-77106-R, AEI/FEDER/UE) projects.

ACKNOWLEDGMENTS

The authors are thankful to Itsas Belarra skipper and crew for their invaluable knowledge and help during the surveys and to Sylvain Capo from Telespazio company for providing the drone images on litter windrows along southeastern French coastline. The actions of local public authorities like Diputación Foral de Gipuzkoa/Gipuzkoako Foru Aldundia, Communauté d'Agglomération Pays Basque, and Marie de Biarritz have also been crucial for this research.This is contribution number 963 of AZTI, Marine Research, Basque Research and Technology Alliance (BRTA).

References

Allsopp, M., Walters, A., Santillo, D., and Johnston, P. (2006). Plastic Debris in the World ' s Oceans. Amsterdam: Greenpeace.

Andrés, A., and Basurko, O. C. (2020). "Report on the socio-economic impact of the project," in Deliverable DC2.1 of Project LIFE LEMA.Sukarrieta, 58.

Borja, A., Amouroux, D., Anschutz, P., Gómez-Gesteira, M., Uyarra, M. C., and Valdés, L. (2019). "Chapter 5 - The Bay of Biscay," in World Seas: An Environmental Evaluation (Second Edition), ed. C. Sheppard (Cambridge, MA: Academic Press), 113–152.

Boyra, G., Martínez, U., Cotano, U., Santos, M., Irigoien, X., and Uriarte, A. (2013).Acoustic surveys for juvenile anchovy in the Bay of Biscay: abundance estimate as an indicator of the next year's recruitment and spatial distribution patterns. ICES J. Mar. Sci. 70, 1354–1368.

Cózar, A., Echevarría, F., González-Gordillo, J. I., Irigoien, X., Úbeda, B., Hernández-León, S., et al. (2014). Plastic debris in the open ocean. Proc. Natl. Acad. Sci. U.S.A. 111, 10239–10244.

Declerck, A., Delpey, M., Rubio, A., Ferrer, L., Basurko, O. C., Mader, J., et al.(2019). Transport of floating marine litter in the coastal area of the southeastern Bay of Biscay: a lagrangian approach using modelling and observations.J. Operat. Oceanogr. 12, S111–S125.

EC. (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (marine strategy framework directive). Off. J. Eur. Union 164, 19–40. doi: 10.1016/j.bios.2004.07.033

Ec. (2019). Directive 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment. Official Journal of the European Union 155, 2-19.

Eea (2018). "Citizens collect plastic and data to protect Europe's marine environment", in: ISSN 2467-3196. (ed.) E.E. Agency.).

Efimova, I., Bagaeva, M., Bagaev, A., Kileso, A., and Chubarenko, I. P. (2018). Secondary microplastics generation in the sea swash zone with coarse bottom sediments: : laboratory experiments. Front. Mar. Sci. 5:313. doi: 10.3389/fmars.2018.00313

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., and Reisser, J. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLOS ONE 9, e111913.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., and Rifman, S. (2013). Plastic pollution in the South Pacific subtropical gyre. Marine Pollution Bulletin 68, 71-76.

Faris, J., and Hart, K. (1995). "Sea of debris: A summary of the Third International Conference on Marine Debris", (ed.) Iucn. (Alaska Fisheries Science Center | Seattle, WA, USA).

Frontiers in Marine Science. (2020). Marine Litter Windrows [online]. Available: https://www.frontiersin.org/research-topics/12854/marine-litter-windrows [Accessed January, 2020]

Gabiña, G., and Basurko, O.C. (2018). "La flota pesquera vasca: estrategias para la mitigación del cambio climático", in: III Cross border conference on climate and coastal change, ed. Azti: Unidad de Investigación Marina de AZTI, 78-81.

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

Galgani, F., Hanke, H., and Werner, S. (2011). Marine litter technical recommendations for the implementation of MSFD requirements, report of the MSFD GES Technical Subgroup on Marine Litter, EUR 25009 EN 2011.

Gesamp (2015). "Sources, fate and effects of microplastics in the marine environment: a global assessment", in: IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90, 96 p. (ed.) P.J. Kershaw.).

IMO (2018). "Action plan to address marine plastic litter from ships," in ANNEX 10 RESOLUTION MEPC.310(73). London. IMO's Marine Environment Protection Committee.http://www.imo.org/en/MediaCentre/HotTopics/marinelitter/Documents/IMO%20marine%20litter%20action%20plan%20MEPC%2073-19-Add-1.pdf

Jambeck, J., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K. (2015). "Plastic waste inputs from land into the ocean. ", in: Science. Vol 347. Issue Number 6223.).

Jeftic, L., Sheavly, S.B., Adler, E., Meith, N., and Programme, U.N.S.R.S. (2009). Marine litter : a global challenge. Nairobi, Kenya: Regional Seas, United Nations Environment Programme

King, P., 2018. Fishing for litter: A cost-benefit analysis of how to abate ocean pollution. ES50064 MRes Dissertation, Department of Economics, University of Bath.

Laiz, I., Ferrer, L., Plomaritis, T.A., and Charria, G. (2014). Effect of river runoff on sea level from in-situ measurements and numerical models in the Bay of Biscay. Deep Sea Research Part II: Topical Studies in Oceanography 106, 49-67.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., and Reddy, C.M. (2010). Plastic Accumulation in the North Atlantic Subtropical Gyre. Science 329, 1185.

Law, K.L., Morét-Ferguson, S.E., Goodwin, D.S., Zettler, E.R., Deforce, E., Kukulka, T., and Proskurowski, G. (2014). Distribution of Surface Plastic Debris in the Eastern Pacific Ocean from an 11-Year Data Set. Environmental Science & Technology 48, 4732-4738.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., and Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports 8, 4666.

Lebreton, L.C.M., Greer, S.D., and Borrero, J.C. (2012). Numerical modelling of floating debris in the world's oceans. Marine Pollution Bulletin 64, 653-661.

Maes, T., Perry, J., Alliji, K., Clarke, C., and Birchenough, S.N.R. (2019). Shades of grey: Marine litter research developments in Europe. Marine Pollution Bulletin 146, 274-281.

McIlgorm, A., Campbell, H. F., & Rule, M. J. (2011). The economic cost and control of marine debris damage in the Asia-Pacific region. Ocean and Coastal Management, 54, 643–651.

Meyerjürgens, J., Badewien, T.H., Garaba, S.P., Wolff, J.-O., and Zielinski, O. (2019). A State-of-the-Art Compact Surface Drifter Reveals Pathways of Floating Marine Litter in the German Bight. Frontiers in Marine Science 6.

Morichon, D., Dailloux, D., Aarninkhof, S., and Abadie, S. (2008). Using a Shore-Based Video System to Hourly Monitor Storm Water Plumes (Adour River, Bay of Biscay). Journal of Coastal Research 24, 133-140.

Ospar (2014). "Marine Litter Regional Action Plan ", (ed.) U.K. Ospar Secretariat.).

Pereiro, D., Souto, C., and Gago, J. (2018). Calibration of a marine floating litter transport model. Journal of Operational Oceanography 11, 125-133.

Ramirez-Llodra, E., De Mol, B., Company, J.B., Coll, M., and Sardà, F. (2013). Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Progress in Oceanography 118, 273-287.

Reker, J., de Carvalho Belchior, C., Royo Gelabert, E., 2015. State of Europe's seas. In: EEA Report. 2 220 pp

Ryan, P. G. (2013). A simple technique for counting marine debris at sea reveals steep litter gradients between the Straits of Malacca and the Bay of Bengal. Mar. Pollut. Bull. 69, 128–136. doi: 10.1016/j.marpolbul.2013.01.016

UNEP (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. Nairobi: UNEP.

Unep and Grid-Arendal (2016). "Marine Litter Vital Graphics., United Nations Environment Programme and GRID-Arendal". (Nairobi and Arendal).

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

Van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J. M., Bagaev, A., et al. (2020). The physical oceanography of the transport of floating marine debris. Environ. Res. Lett. 15:023003. doi: 10.1088/1748-9326/ab6d7d

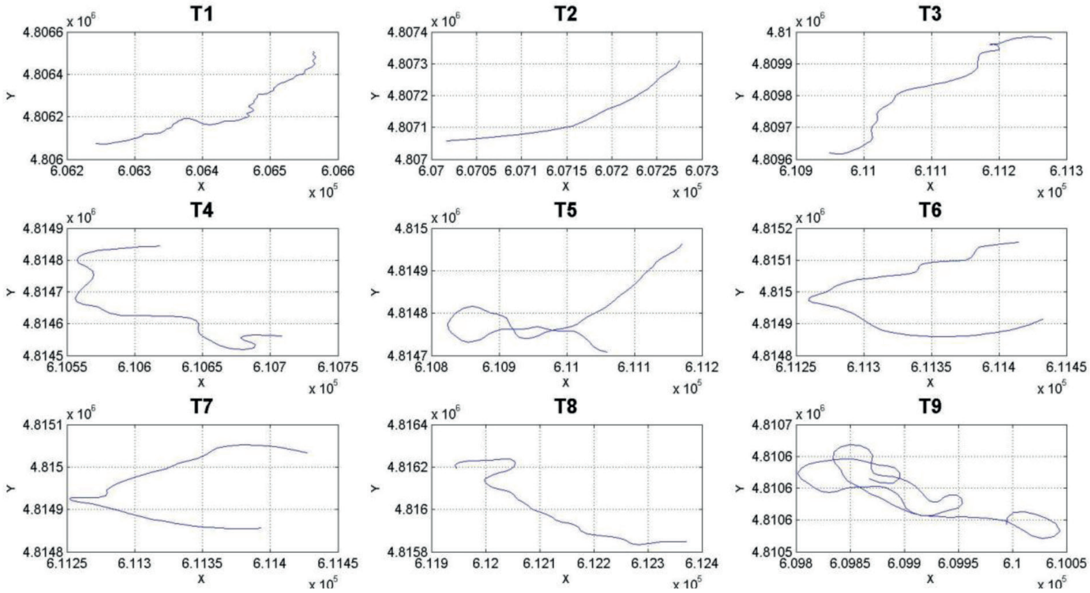
van Sebille, E., England, M. H., and Froyland, G. (2012). Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environ. Res. Lett. 7:044040.

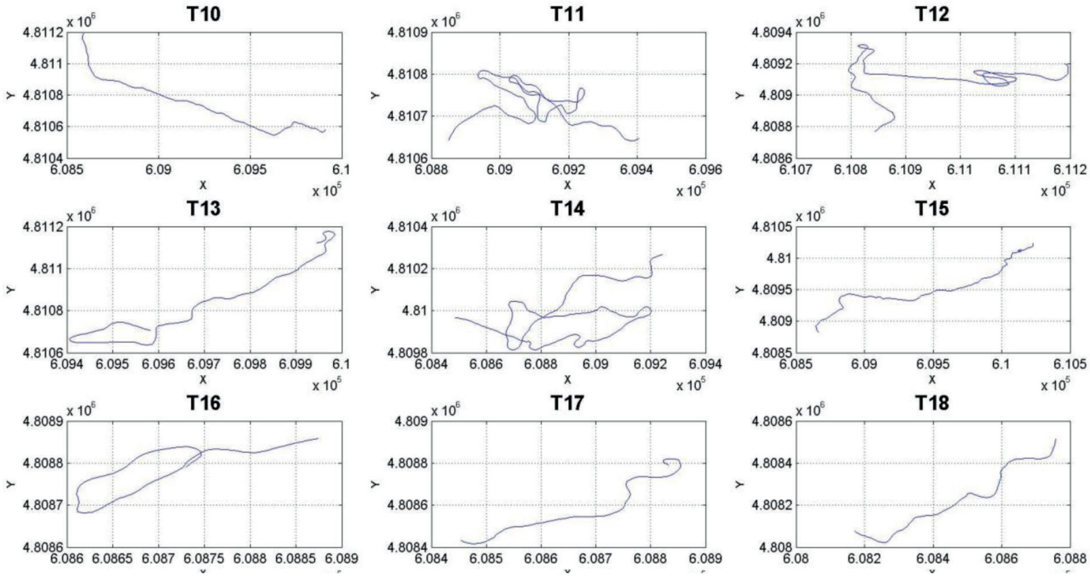
Veiga, J.M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Galgani, F., Thompson, R.C., Dagevos, J., and Gago, J. (2016). "Identifying sources of marine litter. MSFD GES TG Marine Litter Thematic Report", in: JRC Technical Report. MSFD GES TG Marine Litter Thematic Report.EUR 28309.).

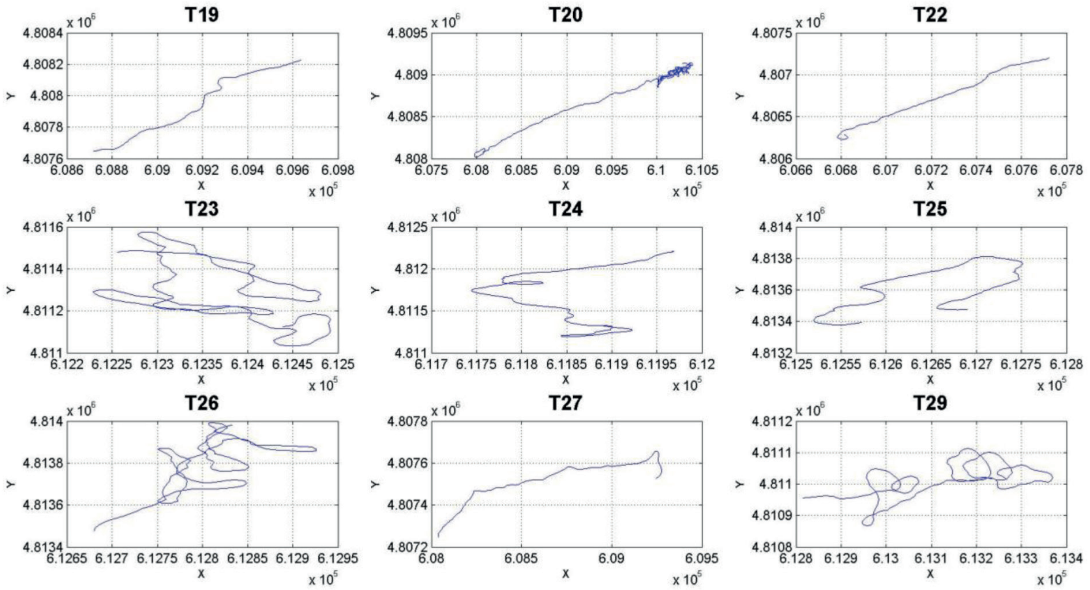
Wei, C.-L., Rowe, G.T., Nunnally, C.C., and Wicksten, M.K. (2012). Anthropogenic "Litter" and macrophyte detritus in the deep Northern Gulf of Mexico. Marine Pollution Bulletin 64, 966-973.

Supplementary material

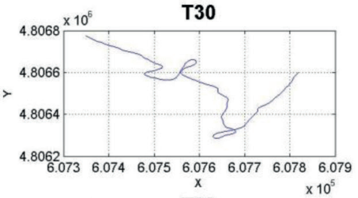
Supplementary Figures 5.2-5.8



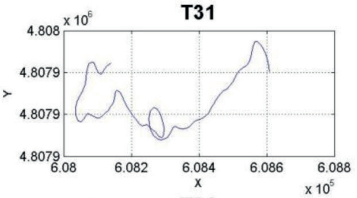




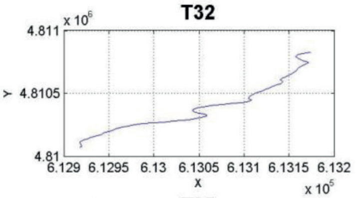
T30



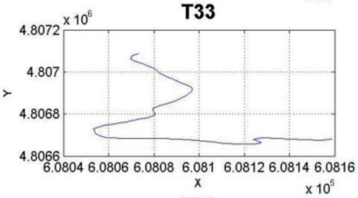
T31



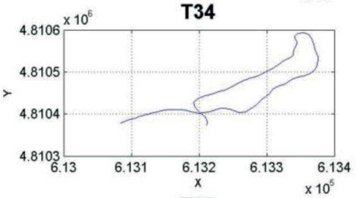
T32



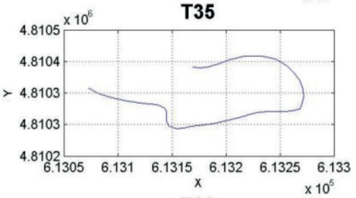
T33



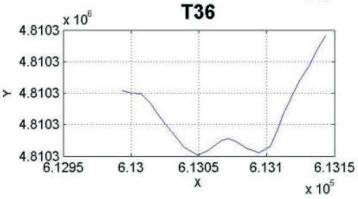
T34



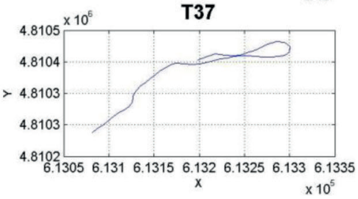
T35



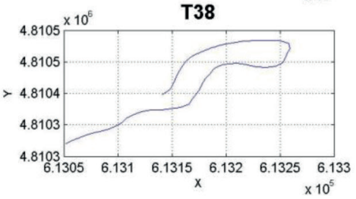
T36



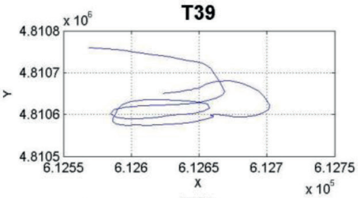
T37



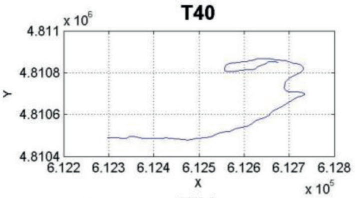
T38



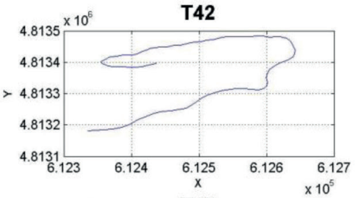
T39



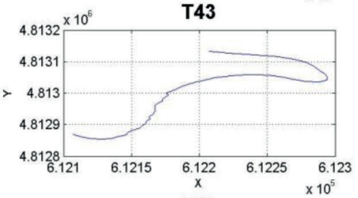
T40



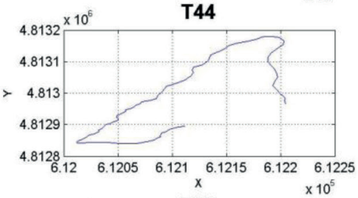
T42



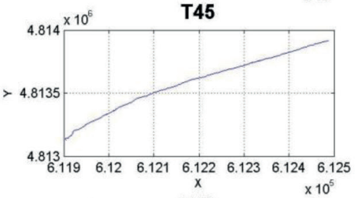
T43



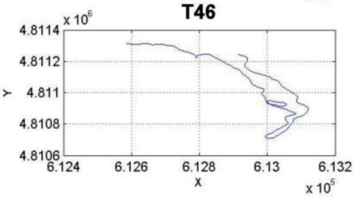
T44



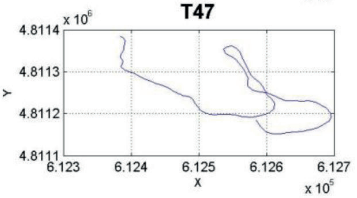
T45



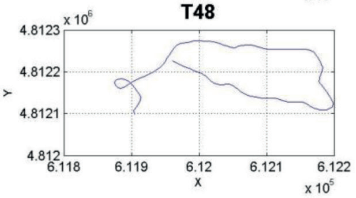
T46



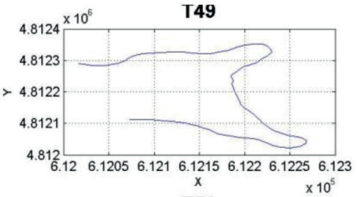
T47



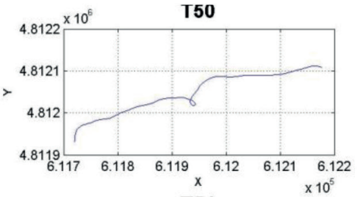
T48



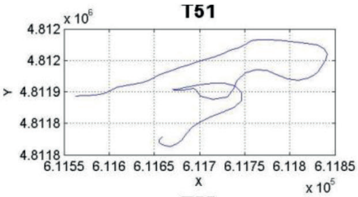
T49



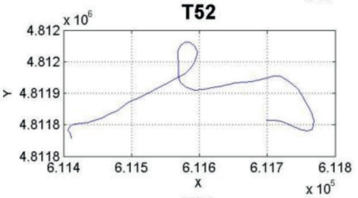
T50



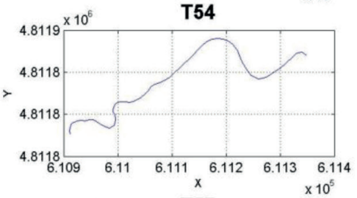
T51



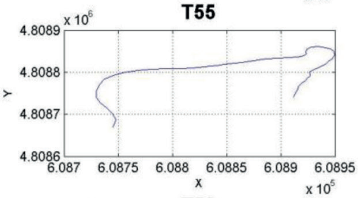
T52



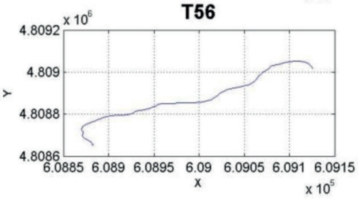
T54



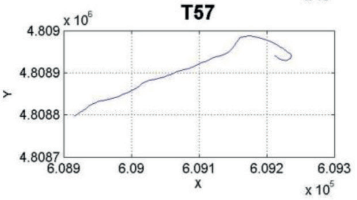
T55



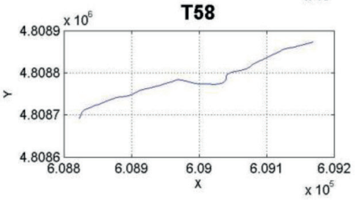
T56

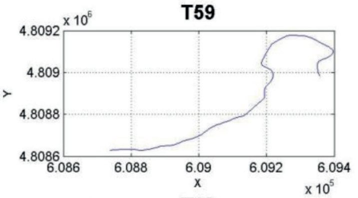


T57

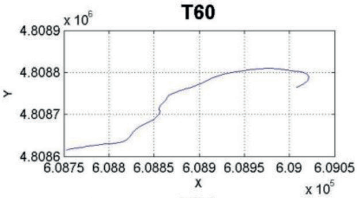


T58

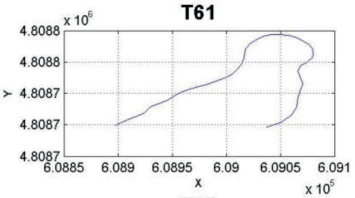




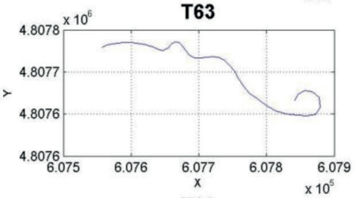
T59



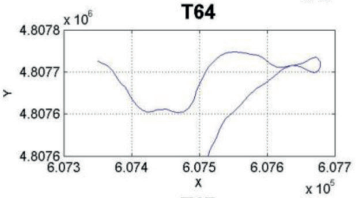
T60



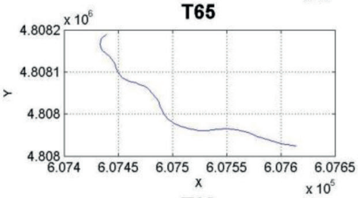
T61



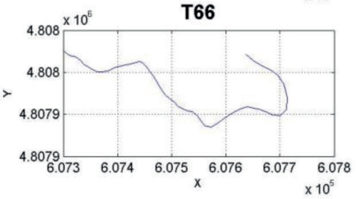
T63



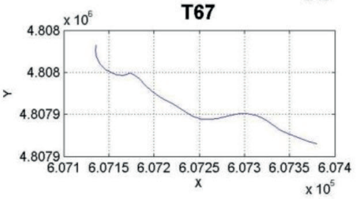
T64



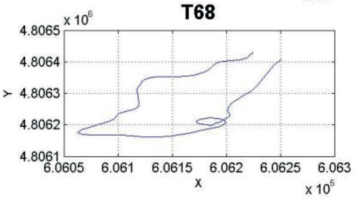
T65



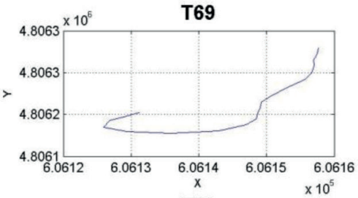
T66



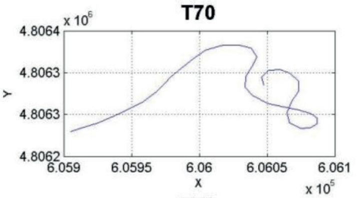
T67



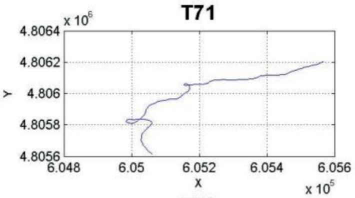
T68



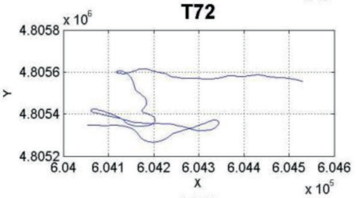
T69



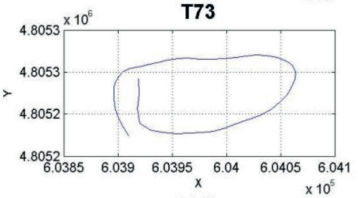
T70



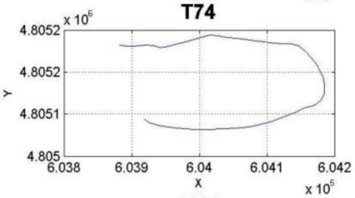
T71



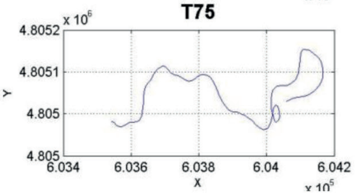
T72



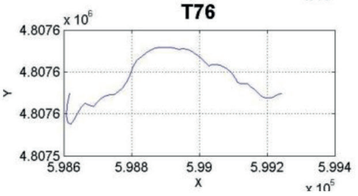
T73



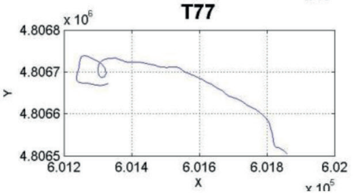
T74



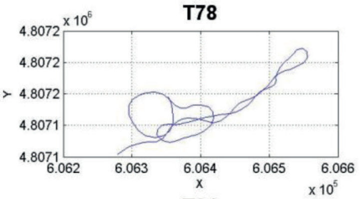
T75



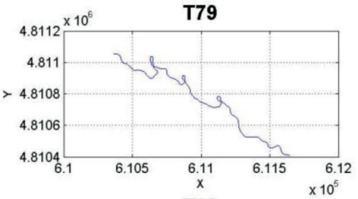
T76



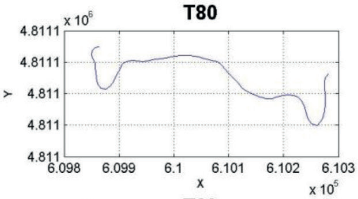
T77



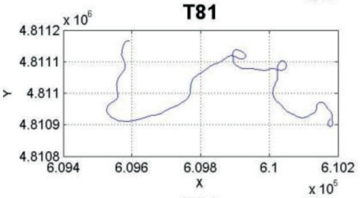
T78



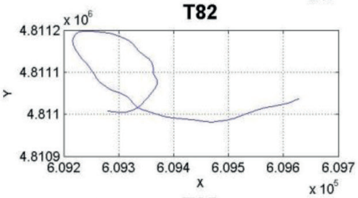
T79



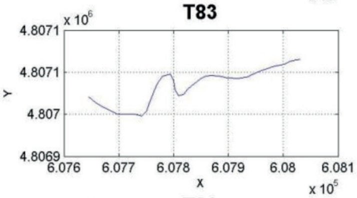
T80



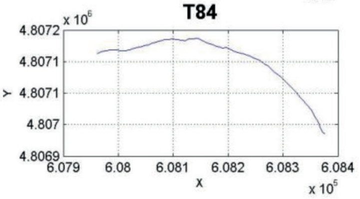
T81



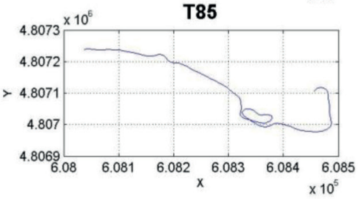
T82



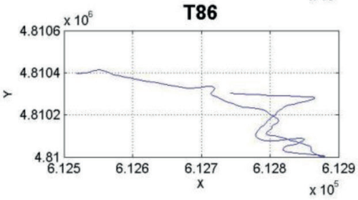
T83



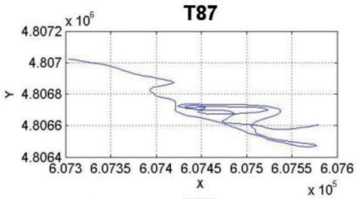
T84

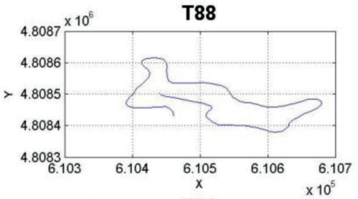


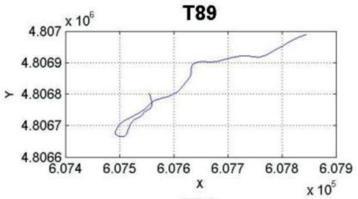
T85

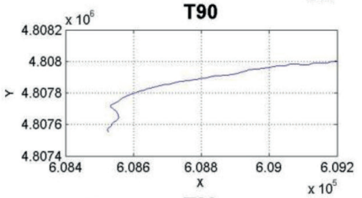


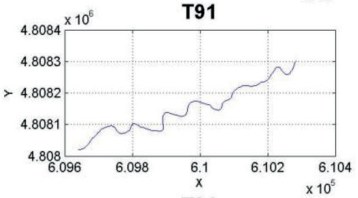
T86

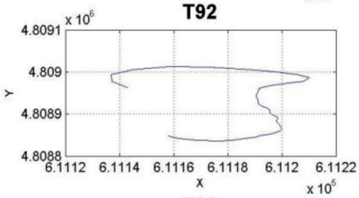

T87

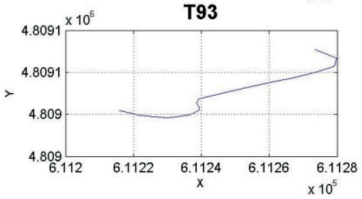

T88

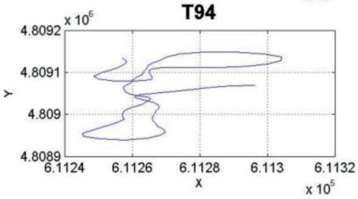

T89

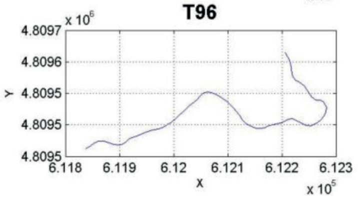

T90

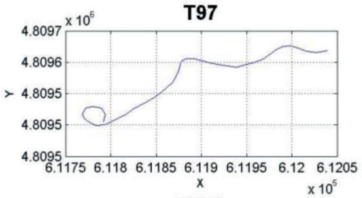

T91

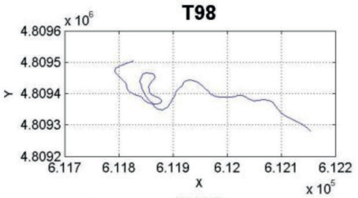

T92

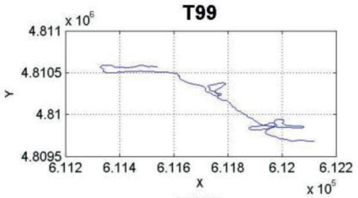

T93

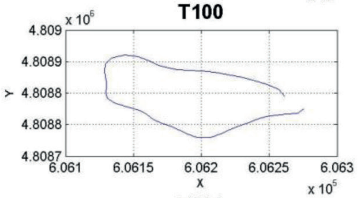

T94

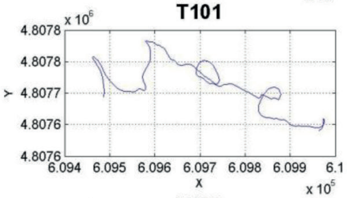

T96

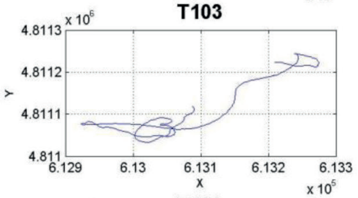

T97

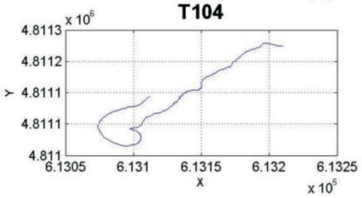

T98

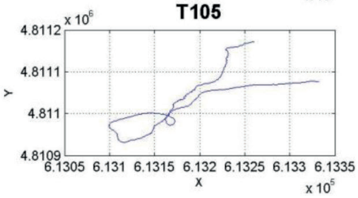

T99

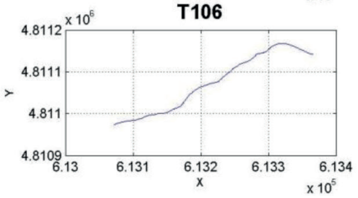

T100

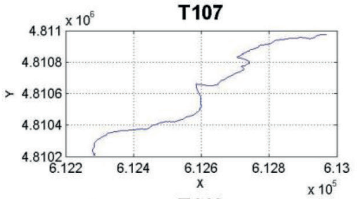

T101

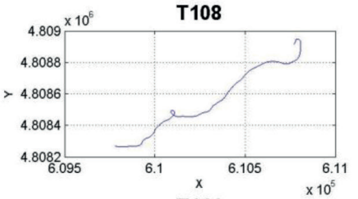

T103

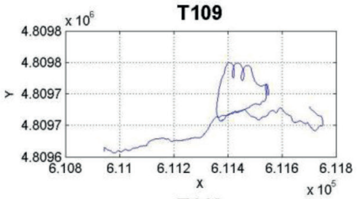

T104

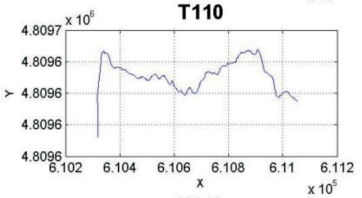

T105

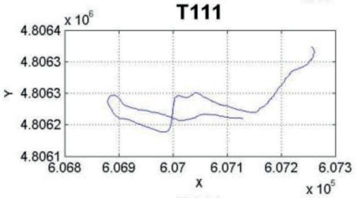

T106

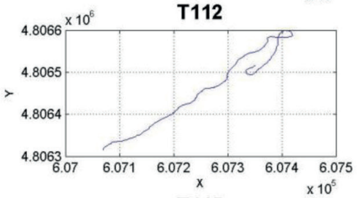

T107

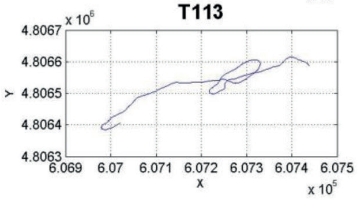

T108

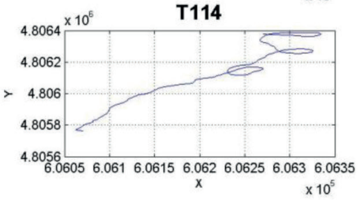

T109

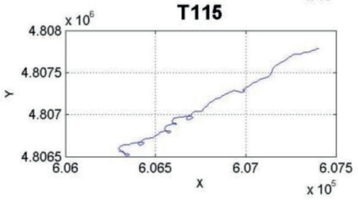

T110


T111

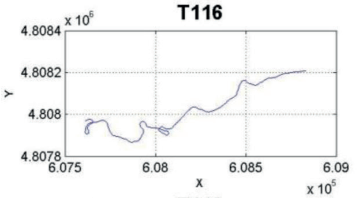

T112


T113

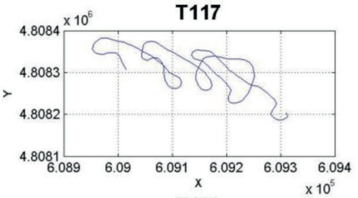

T114


T115

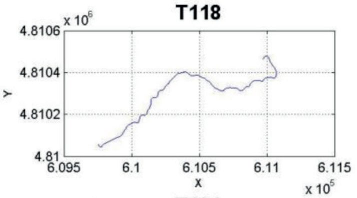
T116



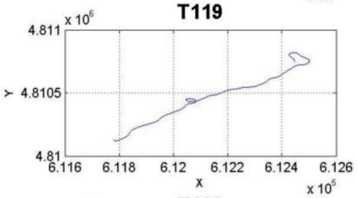
T117



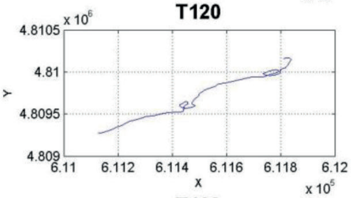
T118



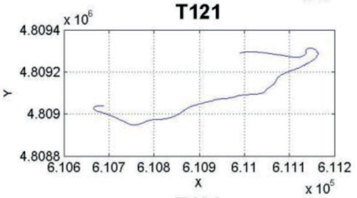
T119



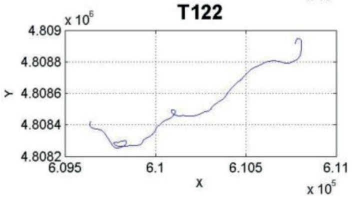
T120



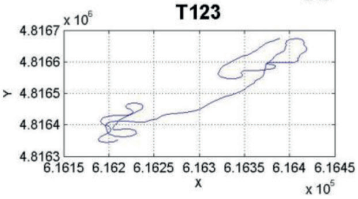
T121



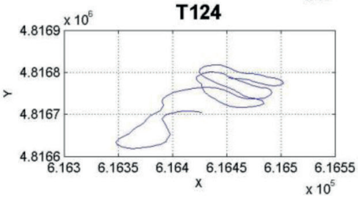
T122



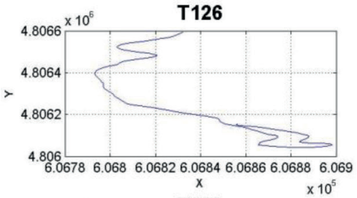
T123



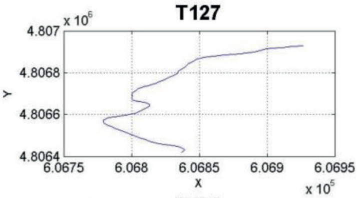
T124



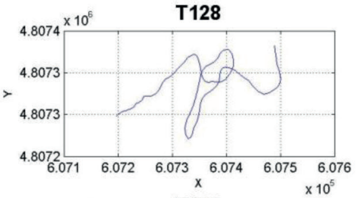
T126



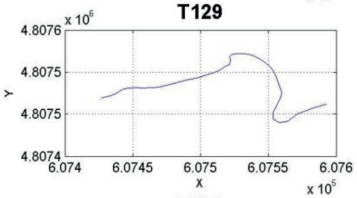
T127



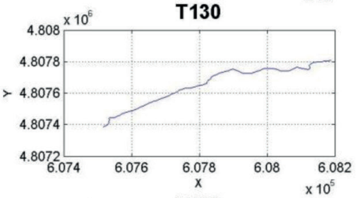
T128



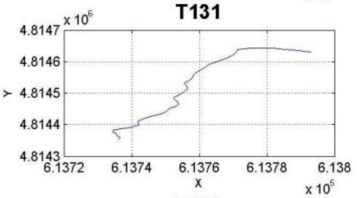
T129



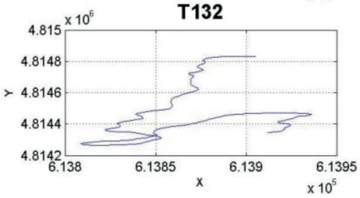
T130



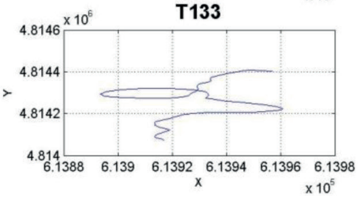
T131



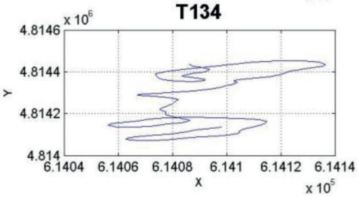
T132



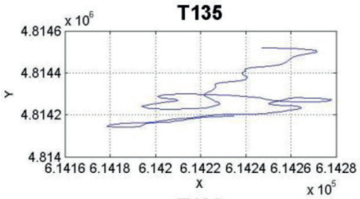
T133



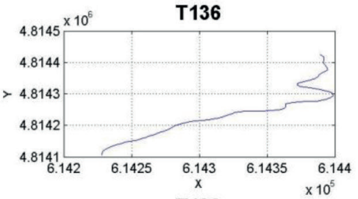
T134



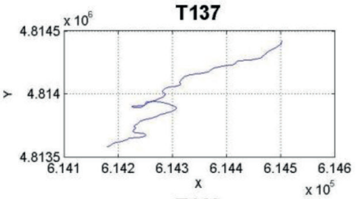
T135



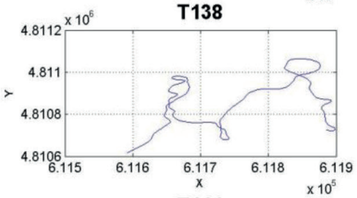
T136



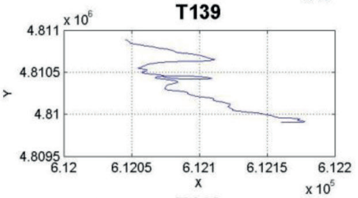
T137



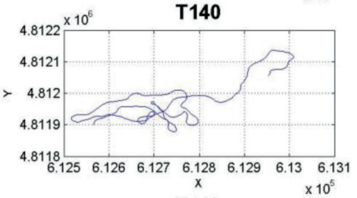
T138



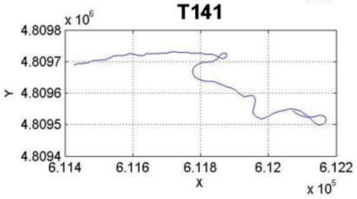
T139



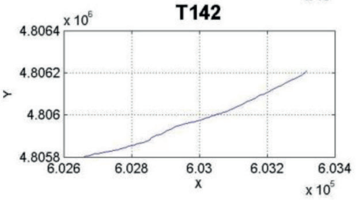
T140



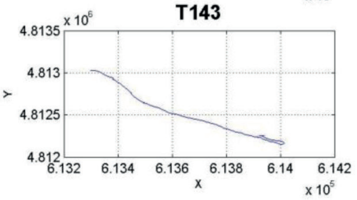
T141

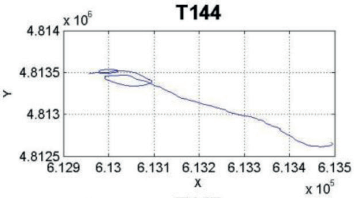


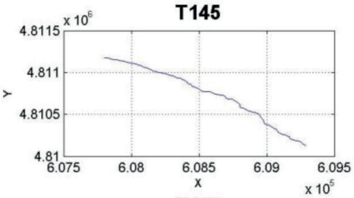
T142

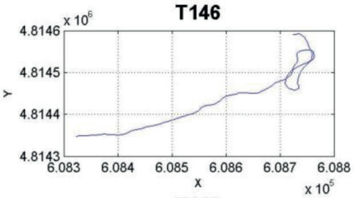


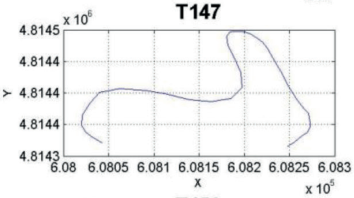
T143

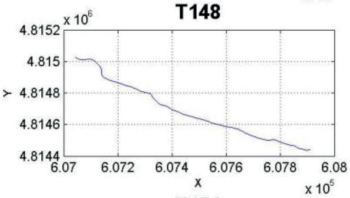


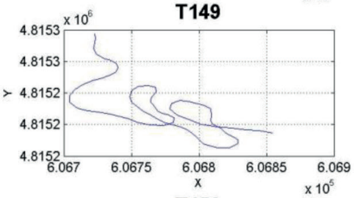

T144
x 10^6
4.814
4.8135
4.813
4.8125
Y
6.129 6.13 6.131 6.132 6.133 6.134 6.135
X
x 10^5

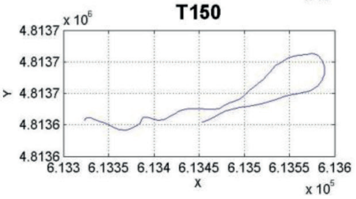

T145
x 10^6
4.8115
4.811
4.8105
4.81
Y
6.075 6.08 6.085 6.09 6.095
X
x 10^5

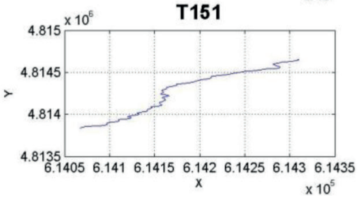

T146
x 10^6
4.8146
4.8145
4.8144
4.8143
Y
6.083 6.084 6.085 6.086 6.087 6.088
X
x 10^5

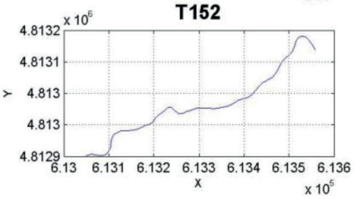

T147
x 10^6
4.8145
4.8144
4.8144
4.8144
4.8143
Y
6.08 6.0805 6.081 6.0815 6.082 6.0825 6.083
X
x 10^5

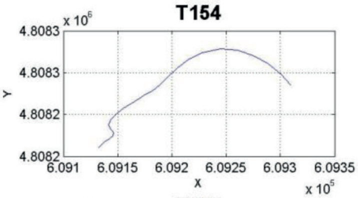

T148
x 10^6
4.8152
4.815
4.8148
4.8146
4.8144
Y
6.07 6.072 6.074 6.076 6.078 6.08
X
x 10^5

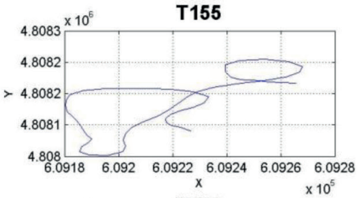

T149
x 10^6
4.8153
4.8153
4.8152
4.8152
4.8152
Y
6.067 6.0675 6.068 6.0685 6.069
X
x 10^5

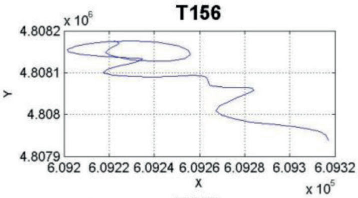

T150
x 10^6
4.8137
4.8137
4.8137
4.8136
4.8136
Y
6.133 6.1335 6.134 6.1345 6.135 6.1355 6.136
X
x 10^5

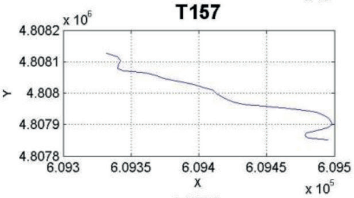

T151
x 10^6
4.815
4.8145
4.814
4.8135
Y
6.1405 6.141 6.1415 6.142 6.1425 6.143 6.1435
X
x 10^5

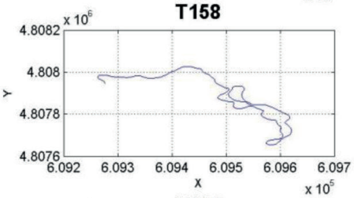

T152
x 10^6
4.8132
4.8131
4.813
4.813
4.8129
Y
6.13 6.131 6.132 6.133 6.134 6.135 6.136
X
x 10^5

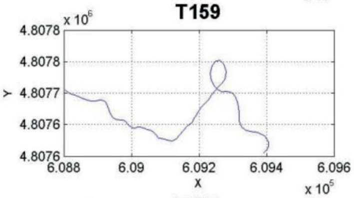

T154
x 10^6
4.8083
4.8083
4.8082
4.8082
Y
6.091 6.0915 6.092 6.0925 6.093 6.0935
X
x 10^5

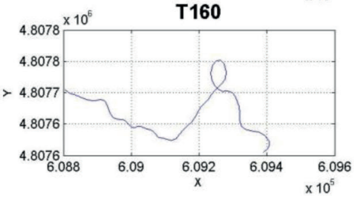

T155
x 10^6
4.8083
4.8082
4.8082
4.8081
4.808
Y
6.0918 6.092 6.0922 6.0924 6.0926 6.0928
X
x 10^5

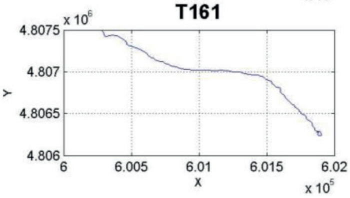

T156
x 10^6
4.8082
4.8081
4.808
4.8079
Y
6.092 6.0922 6.0924 6.0926 6.0928 6.093 6.0932
X
x 10^5

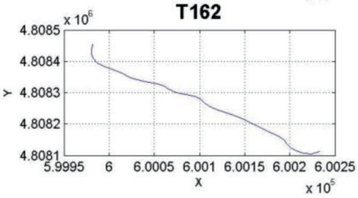

T157
x 10^6
4.8082
4.8081
4.808
4.8079
4.8078
Y
6.093 6.0935 6.094 6.0945 6.095
X
x 10^5

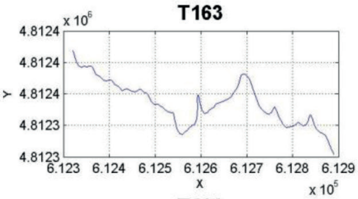

T158
x 10^6
4.8082
4.808
4.8078
4.8076
Y
6.092 6.093 6.094 6.095 6.096 6.097
X
x 10^5

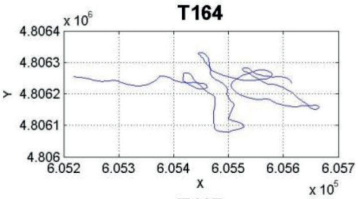

T159
x 10^6
4.8078
4.8078
4.8077
4.8076
4.8076
Y
6.088 6.09 6.092 6.094 6.096
X
x 10^5

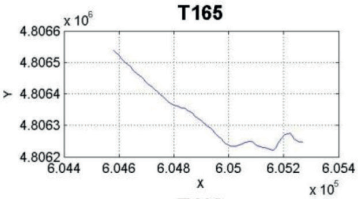

T160
x 10^6
4.8078
4.8078
4.8077
4.8076
4.8076
Y
6.088 6.09 6.092 6.094 6.096
X
x 10^5

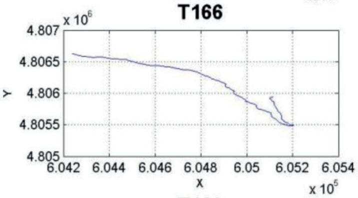

T161
x 10^6
4.8075
4.807
4.8065
4.806
Y
6 6.005 6.01 6.015 6.02
X
x 10^5

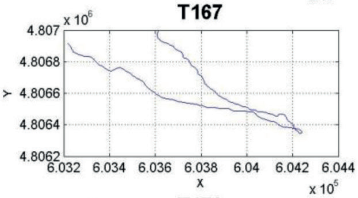

T162
x 10^6
4.8085
4.8084
4.8083
4.8082
4.8081
Y
5.9995 6 6.0005 6.001 6.0015 6.002 6.0025
X
x 10^5

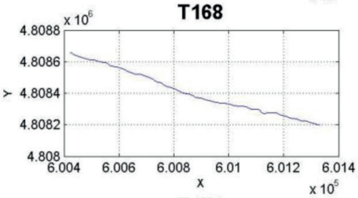

T163
x 10^6
4.8124
4.8124
4.8124
4.8123
4.8123
Y
6.123 6.124 6.125 6.126 6.127 6.128 6.129
X
x 10^5

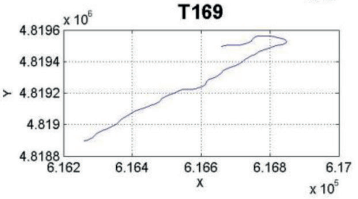

T164
x 10^6
4.8064
4.8063
4.8062
4.8061
4.806
Y
6.052 6.053 6.054 6.055 6.056 6.057
X
x 10^6

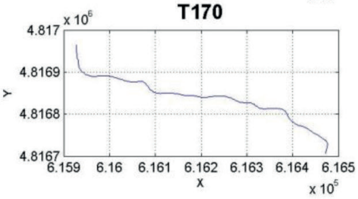

T165
x 10^6
4.8066
4.8065
4.8064
4.8063
4.8062
Y
6.044 6.046 6.048 6.05 6.052 6.054
X
x 10^5

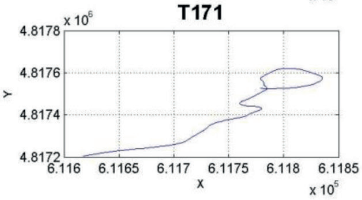

T166
x 10^6
4.807
4.8065
4.806
4.8055
4.805
Y
6.042 6.044 6.046 6.048 6.05 6.052 6.054
X
x 10^5

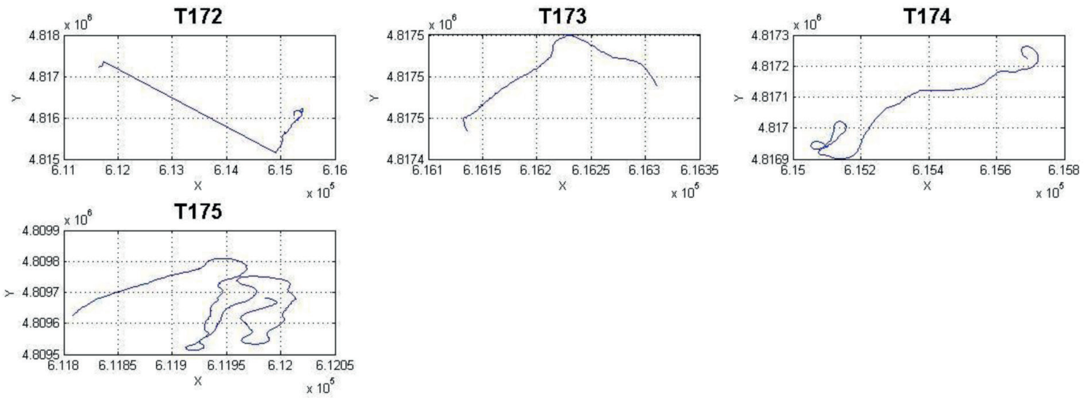

T167
x 10^6
4.807
4.8068
4.8066
4.8064
4.8062
Y
6.032 6.034 6.036 6.038 6.04 6.042 6.044
X
x 10^5


T168
x 10^6
4.8088
4.8086
4.8084
4.8082
4.808
Y
6.004 6.006 6.008 6.01 6.012 6.014
X
x 10^5


T169
x 10^6
4.8196
4.8194
4.8192
4.819
4.8188
Y
6.162 6.164 6.166 6.168 6.17
X
x 10^5

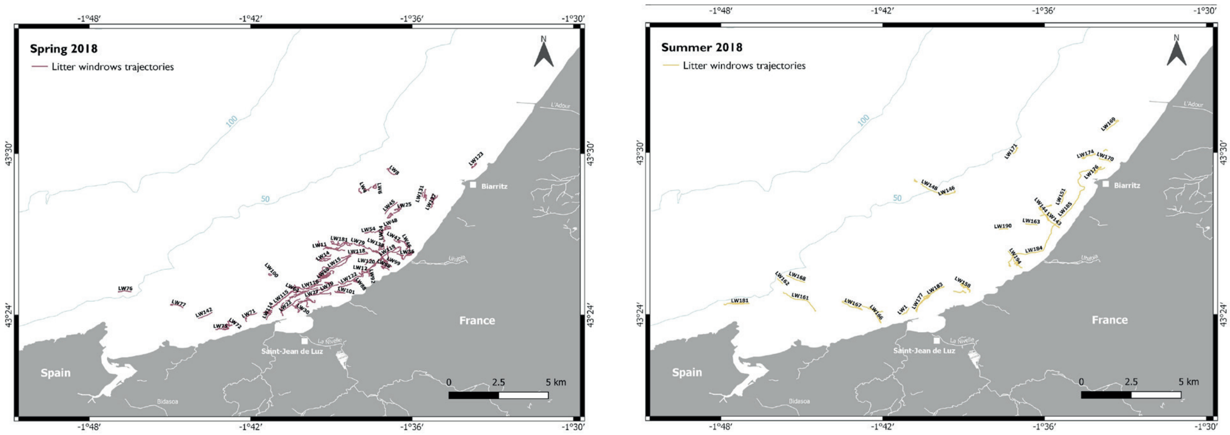

T170
x 10^6
4.817
4.8169
4.8168
4.8167
Y
6.159 6.16 6.161 6.162 6.163 6.164 6.165
X
x 10^5


T171
x 10^6
4.8178
4.8176
4.8174
4.8172
Y
6.116 6.1165 6.117 6.1175 6.118 6.1185
X
x 10^5



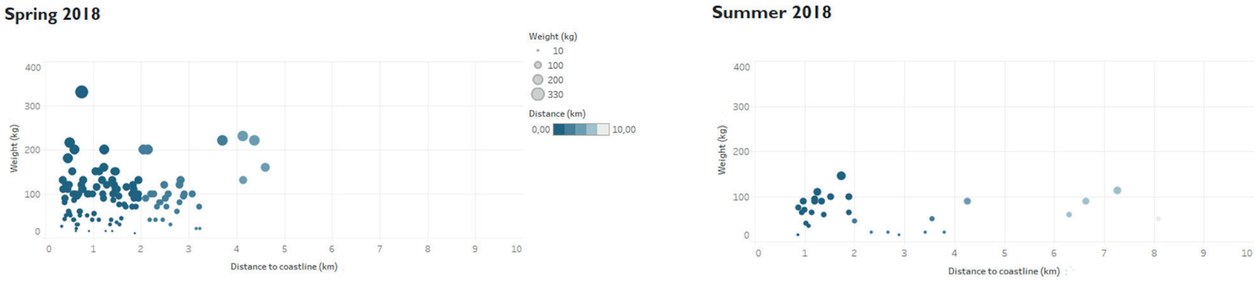
Supplementary Figures 5.2-5.8. Trajectories of the tows (blue line) along the litter windrows during spring and summer 2018. The number at the top corresponds to the number of the tow. Positions are defined by their geographical coordinates.material.spring (left plot) and summer 2018 (right plot).

Supplementary Figure 5.9



Supplementary Figure 5.9. Overview of the positions of the litter windrows during spring 2018 (dark pink line) and summer 2018 (yellow line). The number at the top corresponds to the number of the litter windrow.

Supplementary Figure 5.10



Supplementary Figures 5.10. Distance to coastline of each litter windrow during spring and summer 2018. The distance is established by reference to the center of gravity of the litter windrow.

Supplementary Table 5.8

Supplementary Table 5.8. List of categories of litter items for marine litter characterization. This list is a shortened version of the Master List provided by the MSFD Technical Subgroup on Marine Litter adapted to the occurrence of litter items in study area.

Materials	TSG_ML General code	General name
Plastics - Polystyrene	G1	4/6-pack yokes, six-pack rings
	G2-G3-G4	Bags incl. pieces
	G5	What remains form rip-off plastic bags
	G7-G8	Drink bottles
	G10	Food containers incl. Fast food containers
	G6-G9-G11-G12-G13-G14-G15-G16	Other bottles and plastic containers
	G18	Crates
	G20-G21-G22-G23-G24	Plastic caps and lids/Plastic rings
	G26	Cigarette lighters
	G27	Cigarette butts and filters
	G30-G31	Crisps packets/sweet wrappers and lolly sticks
	G32	Toys and party poppers
	G33	Cups and cup lids
	G34-G35	Cutlery, trays and straws
	G37	Mesh vegetable bags
	G39-G40-G41	Gloves
	G42	Pots, incl pieces
	G43	Tags (fishing and industry)
	G48-G49-G50	String and cords
	G51-G52-G53-G54	Nets and pieces of net
	G56	Tangled nets/cord
	G57	Fish boxes - plastic
	G58	Fish boxes - expanded polystyrene
	G60-G62-G63	Light sticks/Floats for fishing nets/Buoys
	G73-G74	Foam sponge/packaging/insulation/polyurethane
	G79	Plastic pieces 2.5 cm > < 50cm
	G80	Plastic pieces > 50 cm
	G82	Polystyrene pieces 2.5 cm > < 50cm
	G83	Polystyrene pieces> 50 cm
	G66	Strapping bands
	G95	Cotton bud sticks
	G96	Sanitary towels/panty liners/tampons and tampon applicators
	G98-G99-G100	Other sanitary/medical items (e.g diapers, toilet paper, tissue, tubes)
	G71-G102	Plastic shoes
	G123	Polyurethane granules < 5 mm
	G124	Other plastic/polystyrene items (identifiable)

Materials	TSG_ML General code	General name
Rubber	G125	Balloons and balloon sticks
	G126	Balls
	G127	Rubber boots
	G128	Tires and belts
	G134	Other rubber pieces
Cloth	G135-G137	Clothing (clothes, hats, towels)
	G136-G138	Shoes and sandals
	G140	Sacking
	G143	Sails, canvas
	G145	Other (specify)
Paper/ Cardboard	G148	Cardboard (boxes & fragments)
	G149	Paper packaging
	G154	Newspapers & magazine
	G150-G151	Cartons/Tetra pack
	G158	Other paper items
Wood	G160	Pallets
	G161	Wood (processed)
	G162	Crates
	G164	Fish boxes
	G165	Ice-cream sticks, chip forks, chopsticks, toothpicks
	G168	Wooden boards
	G173	Other (specify)
Metal	G174	Sprays
	G175	Cans (beverage)
	G176	Cans (food)
	G177	Foil wrappers, aluminum foil
	G178	Bottle caps, lids & pull tabs
	G182	Fishing related (weights, sinkers, lures, hooks)
	G197	Other
Glass/ Ceramics	G200	Bottles Inc. Pieces
	G208	Glass fragments > 2.5 cm
	G208	Ceramic fragments >2.5 cm

CHAPTER 4

Publication data

Type	Research Paper
Title	Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas
Authors	Irene Ruiz1*, Ana J. Abascal2, Oihane C. Basurko1 and Anna Rubio1
Affiliation	1AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Pasaia, Spain 2IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain
Journal	Environmental Pollution
Year	2022
Volume	292, Part A
Stage of publication	Published

HIGHLIGHTS

01. Fishing-related FML items are modelled considering their buoyancy
02. Highly buoyant items beach after 30 days, only 1% remain floating after 90 days
03. Half of low buoyant items remain floating after 90 days and 20-35% beach
04. Only 20% of items escape the Bay of Biscay, mostly through the northern boundary
05. French MPAs are substantially affected by highly buoyant items

ABSTRACT

Sea-based sources account for 32 - 50% of total marine litter found at the European basins with the fisheries sector comprising almost 65% of litter releases. In the south-east coastal waters of the Bay of Biscay this figure approaches the contribution of just the floating marine litter fraction. This study seeks to enhance knowledge on the distribution patterns of floating marine litter generated by the fisheries sector within the Bay of Biscay and in particular on target priority Marine Protected Areas (MPAs) to reinforce marine litter prevention and mitigation policies. This objective is reached by combining the data on geographical distribution and intensity of fishing activity, long-term historical met-ocean databases, Monte Carlo simulations and Lagrangian modelling with floating marine litter source and abundance estimates for the Bay of Biscay. Results represent trajectories for two groups of fishing-related items considering their exposure to wind; they also provide their concentration within 34 MPAs. Zero windage coefficient is applied for low buoyant items not subjected to wind effect. Highly buoyant items, strongly driven by winds, are forced by currents and winds, using a windage coefficient of 4%. Results show a high temporal variability on the distribution for both groups consistent with the met-ocean conditions in the area. Fishing-related items driven by a high windage coefficient rapidly beach, mainly in summer, and are almost non-existent on the sea surface after 90 days from releasing.

This underlines the importance of windage effect on the coastal accumulation for the Bay of Biscay. Only around 20% of particles escaped through the boundaries for both groups which gives added strength to the notion that the Bay of Biscay acts as accumulation region for marine litter. MPAs located over the French continental shelf experienced the highest concentrations (>75 particles/km2) suggesting their vulnerability and need for additional protection measures.

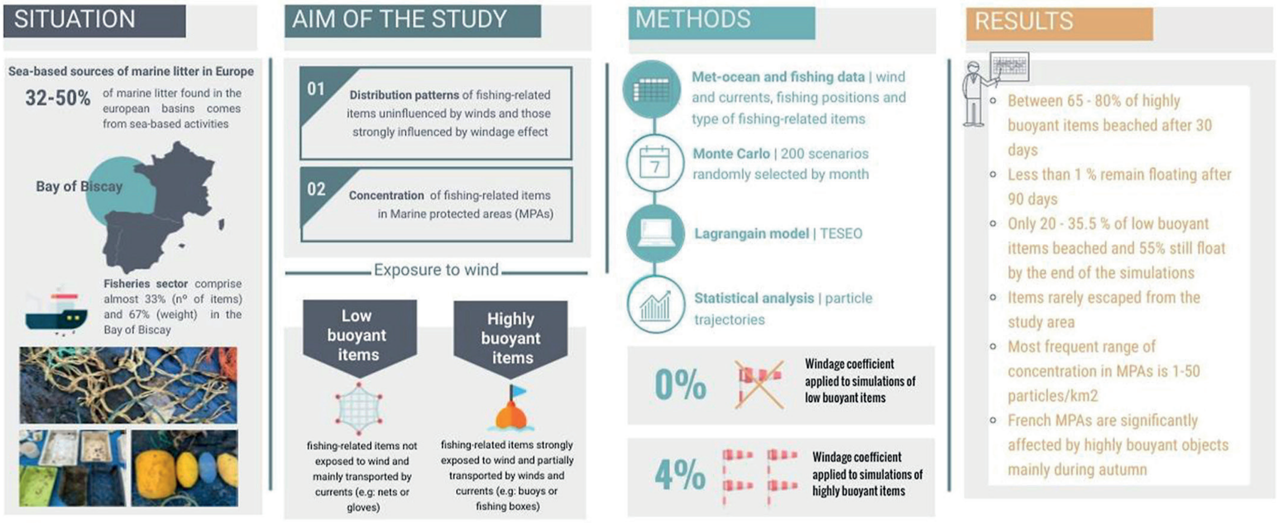
KEY WORDS

Fishing-related floating marine litter; Bay of Biscay; Lagrangian modelling; Windage; Marine protected areas

INTRODUCTION

Worldwide fast-growing levels of marine litter pose a complex and multi-dimensional concern requiring prompt and tailor-made measures and solutions to ensure a real protection for the marine environment. Efforts have been undertaken over the last years to gain a comprehensive understanding on the marine litter issue. They all have plugged significant knowledge gaps and boosted decision-making at national, regional, and international levels. However, despite the increasing research and the political actions achieved, long-term datasets to characterize the sources, define quantities, behaviour and impacts of marine litter are still scarce.

There is a scientific agreement regarding the categorization of sea- and land-based marine litter origins (Galgani et al., 2015; Kershaw et al., 2019; Thushari and Senevirathna, 2020). or the large proportion of marine litter made up of plastic (Cózar et al., 2014; Barboza et al., 2019; Morales-Caselles et al., 2021). Nonetheless, the research made to date reveals a wide disparity between the estimations of plastic litter generated on land entering the ocean (Jambeck et al., 2015; Boucher and Friot, 2017; Ryberg et al., 2018) and the amount of marine litter floating on the ocean surface (Eriksen et al., 2014; van Sebille et al., 2015).



SITUATION

Sea-based sources of marine litter in Europe

32-50% of marine litter found in the european basins comes from sea-based activities

Fisheries sector comprise almost 33% (nº of items) and 67% (weight) in the Bay of Biscay

AIM OF THE STUDY

01 **Distribution patterns** of fishing-related items uninfluenced by winds and those strongly influenced by windage effect

02 **Concentration** of fishing-related items in Marine protected areas (MPAs)

Exposure to wind

Low buoyant items

fishing-related items not exposed to wind and mainly transported by currents (e.g: nets or gloves)

Highly buoyant items

fishing-related items strongly exposed to wind and partially transported by winds and currents (e.g: buoys or fishing boxes)

METHODS

Met-ocean and fishing data | wind and currents, fishing positions and type of fishing-related items

Monte Carlo | 200 scenarios randomly selected by month

Lagrangain model | TESEO

Statistical analysis | particle trajectories

0% Windage coefficient applied to simulations of low buoyant items

4% Windage coefficient applied to simulations of highly buoyant items

RESULTS

- Between 65 - 80% of highly buoyant items beached after 30 days
- Less than 1 % remain floating after 90 days
- Only 20 - 35.5 % of low buoyant ittems beached and 55% still float by the end of the simulations
- Items rarely escaped from the study area
- Most frequent range of concentration in MPAs is 1-50 particles/km2
- French MPAs are significantly affected by highly bouyant objects mainly during autumn

Fig 5.16 Graphical abstract

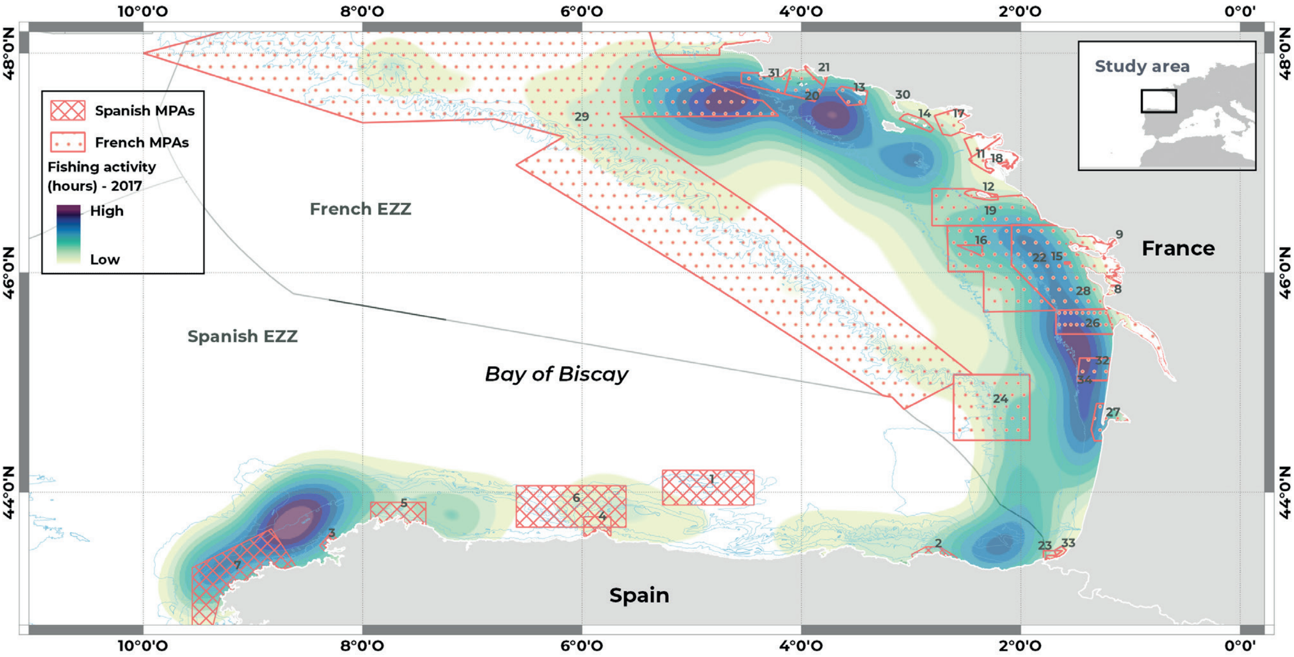


Fig 5.17. Area of study with the location of the selected Marine Protected Areas (MPAs) - Spanish MPAs in polygons with crosses and French MPAs in polygons with dots-. Numbers correspond to the name of each MPA in Table 5.7.

Besides, the vast majority of the studies have focused on land-based sources overshadowing marine litter contribution resulting from sea-based activities (Kershaw et al., 2020). It is broadly accepted that land-based sources account for 78 % of marine litter in the world's oceans, while at least the 22 % is originated from sea-based sources (UNEP, 2014; Li et al., 2016; Pawar et al., 2016). However, studies documenting the actual released quantities and the differences on litter origins between marine regions are still limited (Sherrington et al., 2016; UNEP, 2016; Morales-Caselles et al., 2021). At European level, sea-based sources account for over 40 % litter items in some regions causing 20–40 % of the total marine litter input by weight (Sherrington et al., 2016; Veiga et al., 2016). Sea-based sources can be dominated by the fisheries and shipping sectors in certain marine areas; overall 70 % by weight of floating marine litter (hereinafter FML) in the open ocean is fishing-related (Eriksen et al., 2014; UNEP, 2016). Surveys undertaken on European beaches accounted for 3–15 % of fishing-related items (Addamo et al., 2017) reaching 17 % in the North-East Atlantic region (OSPAR, 2020).

In the less explored Bay of Biscay (hereinafter BoB) region, fisheries and aquaculture sectors represents the source of the 14–38 % of the total items recorded for Spanish beaches, 50 % for French beaches (Gago, 2014; Rayon-Viña et al., 2018), and the 35 % (in number of items) or the 55 % (in weight) of the FML (Ruiz et al., 2020). However, these percentage values can vary depending on the geographical origin, the transport mechanisms, the pathways or the durability of the fishing items and can even increase in areas with intensive fishing activities (Veiga et al., 2016).

MPAs are globally recognised to safeguard marine ecosystems and biodiversity by balancing ecological constraints and economic activities (EEA, 2018). They are defined as geographical zones with management objectives oriented to regulate human activities (e.g: fishing, dredging) for a long-term protection and conservation of the marine environment (Day et al., 2012). However, MPAs are exposed to the same levels of marine pollution as non-protected areas since the spatial delimitation of MPAs does not represent an effective impediment to avoid marine litter presence (Nelms et al., 2020). Initiatives to assess the environmental and socio-economic impact of sea-based sources can be of particular interest for establishing policy priorities and effective regulations in MPAs (Fossi and Panti, 2020; Purba et al., 2020). Yet, research on the occurrence, sources and distribution of marine litter in MPAs is patchy and, in some cases, limited to remote locations (Barnes et al., 2018; Luna-Jorquera et al., 2019). However, it has been observed that in North-East Atlantic and Mediterranean based MPAs, fishing and shipping related marine litter represented over 55 %–88 % of the total litter abundance (La Beur et al., 2019; Liubartseva et al., 2019; Luna-Jorquera et al., 2019). Fishing litter and, in particular, derelict abandoned, lost and discarded fishing gear (ALDFG) impacts endangered species and benthic environment, and favours a long duration of ghost fishing efficiency (Macfadyen et al., 2009; Gilman et al., 2021). Recent studies estimate that 5.7 % of all fishing nets, 8.6 % of all traps and 29 % of all lines are lost to the world's ocean annually (Richardson et al., 2019) and the damage caused to marine invertebrates, such as gorgonians and coralligenous biocenosis, has been already documented for the Mediterranean MPAs (Consoli et al., 2019; Betti et al., 2020).

Despite the ocean surface is the best sampled oceanic compartment, the observations made so far are insufficient to predict accurately the transport and destination of FML. The relative immensity of the ocean and the spatio-temporal variability of the circulation and transport processes hinder the research of FML distribution (Hardesty et al., 2016; Maximenko et al., 2019). Thus, modelling approaches can be useful to gain a better understanding of FML behaviour when few observations are available. They provide insights into circulation patterns and support the identification of accumulation zones. A broad variety of FML modelling approaches has been undertaken up till now, from models oriented to simulate litter destination and origin at global scale (Lebreton et al., 2012; Chassignet et al., 2021; Onink et al., 2021) to regional models with higher spatiotemporal resolutions and more reduces coverage such those applied in the Mediterranean Sea (Liubartseva et al., 2018b; Macias et al., 2019; Politikos et al., 2020), the Black Sea

(Stanev and Ricker, 2019; Miladinova et al., 2020), the North Sea (Neumann et al., 2014) or the Adriatic Sea (Liubartseva et al., 2016). Also the application of three-dimensional models simulating the dynamic behaviour of FML is also becoming increasingly widespread (Jalón-Rojas et al., 2019; van Gennip and et al., 2019; Soto-Navarro et al., 2020). In particular, Lagrangian particle tracking techniques have turned out to be an effective approach to solve for FML trajectories using statistical long term database of winds and currents (Hardesty et al., 2017; Van Sebille et al., 2018b). Besides, their capability to incorporate additional parametrizations makes them suited for addressing the direct effect of wind ("windage" as defined by Breivik et al. (2011)) on destination and travel time for different items (NOAA, 2016), as verified by the FML simulation results from the Great Japan Tsunami of 2011 (Maximenko et al., 2018). Object windage classification and parametrization also contributes to identify accurately the potential source regions of FML reaching the coastal areas (Duhec et al., 2015). Even then, the majority of the literature focuses on transport modelling of buoyant and fully submerged objects induced only by surface currents with a global (Lebreton et al., 2012; van Sebille et al., 2015) and regional application (Zambianchi et al., 2017; Miladinova et al., 2020; Politikos et al., 2020).

In the BoB, recent modelling studies have helped to shed some light on the regional circulation of FML. Results emphasize the hypothesis of the Bay being a FML accumulation zone and draw the attention on the high seasonal variability of FML transport (Pereiro et al., 2018; Declerck et al., 2019; Pereiro et al., 2019). Additional research accounting for windage effect highlight the importance of the size of the items on FML entrapment, particularly for the larger ones (>5 mm), more likely to stay in nearshore areas and beached (Rodríguez-Díaz et al., 2020).

However, many questions remain unanswered on FML transport and accumulation patterns based on the origin, windage parametrizations and the subsequent impacts on the marine environment and MPAs. Within this context and to better response to anthropogenic stressors for the coastal waters of the Bay of Biscay in the framework of JERICO-S3 project, the objective of this study is twofold: (1) to provide insights into distribution patterns of fishing-related items uninfluenced by winds and those strongly influenced by windage effect and (2) to assess their concentration in MPAs to put in place future-oriented and effective management and conservation strategies.

STUDY AREA

The study area is located within the OSPAR region IV Bay of Biscay and Iberian Coast and covers the large part of the FAO region Bay of Biscay (subarea 27.8 of FAO major area 27). It extends from 43°N to 48°N and from 11°W to the Spanish and French coastlines (Fig 5.17) and comprises the Spanish and French marine waters defined by the Economic Exclusive Zone (EZZ) boundary.

Intense fishing activities occurred in the study area fostered by the primary production levels and the topographic characteristics of the shelf basin (Lavin et al., 2006). The most common fishing fleet are trawlers together with set longliners and purse seiners since they represent 60–75 % of the fishing hours in the BoB (Fernandes et al., 2019). Fishing activity has become a relatively important human pressure in the BoB and ALDFG has been identified as a hazard for marine mammal populations resulting in fishing mortalities due to their ability to continue to fish target and non-target species (ICES, 2016; Borja et al., 2019).

The circulation in the BoB enhances the seasonal dispersion patterns of FML with high wind drifts south-eastward in winter and north-westward in summer (Borja et al., 2019; Pereiro et al., 2019). The coastline influences the less variable circulation in the inner shelf of the BoB compared to the outer shelf, where variability associated with mesoscale activity govern FML behaviour (Solabarrieta et al., 2014; Pereiro et al., 2018). FML tends to accumulate in the southeast of the Bay during spring and summer with longer residence times comparing to the north-western Iberian coastal waters. During autumn and winter, the northward transport contributes to the dispersion along the French coast (Declerck et al., 2019; Rubio, 2020).

The study area encompasses 34 MPAs - 27 in France and 7 in Spain – aiming to protect mainly benthic habitats, marine mammals and seabirds. Their surface extension range between 26 and 8192 km2 and the average size per MPA is 3442 km2 (Table 5.7). The MPAs considered in this study are predominantly or entirely marine protected areas assigned by UNEP-WCMC (UNEP-WCMC, 2019) and established under the framework of the EU nature Directives, national designations and Regional Sea Conventions (RSCs) (Agnesi et al., 2020).

DATA AND MODELLING METHODOLOGY

Modelling rationale

Fishing-related FML data obtained in sea surveys were combined with met-ocean datasets to model fishing-related FML trajectories (Fig 5.18). Information derived from FML samples was used to categorize the items collected into two groups: low buoyant objects driven by currents and highly buoyant objects driven by wind and currents. Incorporating windage effect allowed the parameters of the model to be adjusted so the modelled outputs agree more closely with the real trajectories of the items. Measurements of fishing effort (hours spent by vessels catching fish) were used for setting the starting locations (sources) of particles carried by currents and wind. The number of particles released per group was proportional to the amount of low and highly buoyant fishing-related items collected in sea surveys. Particles were monthly distributed in the starting locations according to the fishing effort in the region. Particles were initialized randomly every month (from January to December) over a one-year period and their evolution was tracked for 90 days. The two sets of trajectories were post-processed considering the fate of the particles: escaped through the boundaries of the study area (northern, southern, or western boundary) or remained (floating or beached). Results provided the fishing FML distribution patterns and concentration in MPAs.

Fishing-related FML data

FML data were gathered from marine litter windrows - concept described in Cózar et al. (2021) - over Spring and Summer 2018 on the coastal waters of the BoB. Marine litter windrows were detected by visual observations, and, straight after, net tows were carried out along the litter windrow following the streak of higher FML concentration. The FML was stored in 1 m3 big bags and a portion from the collected FML (≈0.2 m3) was randomly retrieved as a sample for the characterization (for further information on the methodology see Ruiz et al. (2020)).

Table 5.7. Marine Protected Areas (MPAs) within the study area. ID indicates the MPA in Fig 5.17.

ID	Name	Area (km2)	Location	Designation
1	El Cachucho	2349.503	ESP	Marine Protected Area
2	Espacio marino de la Ria de Mundaka-Cabo de Ogoño	175	ESP	Marine Protected Area (OSPAR)
3	Espacio marino de la Costa de Ferrolterra - Valdoviño	68	ESP	Marine Protected Area (OSPAR)
4	Espacio marino de Cabo Peñas	320.6099	ESP	Special Protection Area (Birds Directive)
5	Espacio marino de Punta de Candelaria-Ría de Ortigueira-Estaca de Bares	771.5168	ESP	Special Protection Area (Birds Directive)
6	Sistema de cañones submarinos de Avilés	3390	ESP	Marine Protected Area (OSPAR)
7	Espacio marino de la Costa da Morte	3162.8305	ESP	National Nature Reserve
8	Moëze-Oléron	67.19382	FRA	National Nature Reserve
9	Baie De L'Aiguillon (Charente-Maritime)	26	FRA	Marine Nature Park
10	Iroise	3500	FRA	Site of Community Importance (Habitats Directive)
11	Estuaire de la Loire Nord	307.14	FRA	Site of Community Importance (Habitats Directive)
12	Plateau rocheux de l'île d'Yeu	119.98	FRA	Site of Community Importance (Habitats Directive)
13	Ile de Groix	283.3697	FRA	Site of Community Importance (Habitats Directive)
14	Iles Houat-Hoëdic	177.6983	FRA	Site of Community Importance (Habitats Directive)
15	Pertuis Charentais	4560.27	FRA	Site of Community Importance (Habitats Directive)
16	Plateau de Rochebonne	97.15	FRA	Special Protection Area (Birds Directive)
17	Mor Braz	402.76	FRA	Special Protection Area (Birds Directive)
18	Estuaire de la Loire - Baie de Bourgneuf	802.02	FRA	Special Protection Area (Birds Directive)
19	Secteur marin de l'île d'Yeu jusqu'au continent	2454.1	FRA	Special Protection Area (Birds Directive)
20	Archipel des Glénan	587.9	FRA	Special Protection Area (Birds Directive)
21	Dunes et côtes de Trévignon	98.74	FRA	Special Protection Area (Birds Directive)
22	Pertuis charentais - Rochebonne	8192.58	FRA	Special Protection Area (Birds Directive)
23	Estuaire de la Bidassoa et baie de Fontarabie	94.57	FRA	Special Protection Area (Birds Directive)
24	Tête de Canyon du Cap Ferret	3656.39	FRA	Marine Protected Area (OSPAR)
25	Marais de Moëze	67	FRA	Marine Protected Area (OSPAR)
26	Panache de la Gironde et plateau rocheux de Cordouan	952	FRA	Marine Nature Park
27	Bassin D'Arcachon	435	FRA	Marine Nature Park
28	Estuaire De La Gironde et mer des Pertuis	6500	FRA	Special Protection Area (Birds Directive)
29	Mers Celtiques - Talus du golfe de Gascogne	71860.94	FRA	Special Protection Area (Birds Directive)
30	Baie de Quiberon	9.05	FRA	Special Protection Area (Birds Directive)
31	Roches de Penmarc'h	457.28	FRA	Special Protection Area (Birds Directive)
32	Au droit de l'étang d'Hourtin-Carcans	507.16	FRA	Special Protection Area (Birds Directive)
33	Côte Basque rocheuse et extension au large	78	FRA	Marine Protected Area (OSPAR)
34	Portion du littoral sableux de la côte aquitaine	507	FRA	Marine Protected Area (OSPAR)

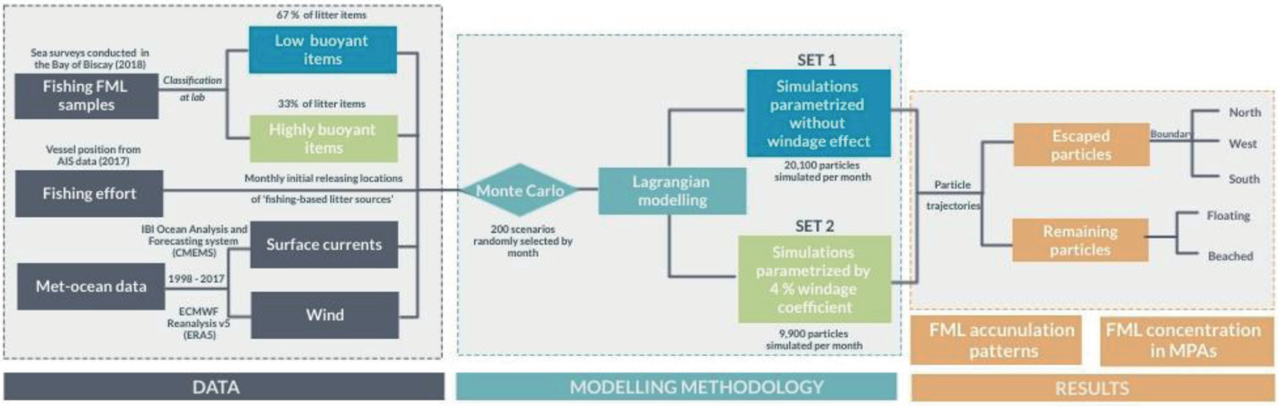


Fig. 5.18. Methodological framework for assess fishing-related floating marine litter distribution and concentration within the Bay of Biscay and Marine Protected Areas.

In total 11 samples were gathered. Origins and characteristics of the items collected in the windrows showcased the fishing contribution to FML in the area. Over 115 kg and 1400 sea-based litter items were classified into two groups considering their exposure to wind (Table 5.8):

- Low buoyant items: items not exposed to wind and mainly transported by currents (e.g: nets or gloves). In total, 1384 items and 77.16 kg in weight.
- Highly buoyant items: items strongly exposed to wind and partially transported by winds and currents (e.g: buoys or fishing boxes). In total, 70 items and 37.94 kg.

The division was chosen based on existing FML windage classification approaches (Yoon et al., 2010; Neumann et al., 2014; Duhec et al., 2015; Maximenko et al., 2018; Pereiro et al., 2019). The classification was refined by adding new items not included in previously studies in order to simulate all fishing-related items collected in the surveys.

Shipping related items were assigned to the fishing category due to their small contribution to FML in the samples. The classification in terms of weight was the basis for allocating the number of particles to the simulation sets. From the released particles, 67 % (241,200) were parameterized to simulate the trajectories with a zero windage coefficient (Set 1; Cd = 0); 33 % of the particles (118,800) were released and run with a high windage coefficient (Set 2; Cd = 4 %).

Input on location of fishing FML sources is crucial for modelling transport and accumulation; thus, the release locations were carefully selected, identifying as 'initial point of fishing-based litter sources' the reported monthly AIS fishing positions corresponding to fishing effort measured on a regular grid of 0.01° within the FAO region Bay of Biscay (subarea 27.8 of FAO major area 27) for 2017. These values exclude the time spent searching for fish and transit periods (see Taconet et al. (2019) for details). Over one million fishing hours and their corresponding vessel positions were considered in the analysis.

Table 5.8. Fishing – related items classification based on the exposure to wind effect. Data were gathered from surveys carried out during Spring and Summer 2018 in the south-east coastal waters of the Bay of Biscay.

TSG_ML General code	General name	Number of items	Weight (kg)
Low buoyant items transported by currents			
G39; G40; G41	Gloves	2	0.16
G42	Pots Inc. Pieces	15	1.81
G43	Tags (fishing and industry)	11	0.26
G48; G49; G50	String and cords	1,165	3.14
G51; G52; G53; G54	Nets and pieces of net	28	52.28
G56	Tangled nets and cords	98	17.31
G66	Strapping bands	61	0.2
G127	Rubber boots	2	2
G182	Fishing related (weights, sinkers, lures, hooks)	2	0.02
	Total	**94.99%**	**67.04%**
Highly buoyant items transported by wind and currents			
G57	Fish boxes - plastic	16	17.65
G58	Fish boxes – expanded polystyrene	5	0.9
G60; G62; G63	Light sticks/Floats for fishing nets/Buoys	23	18.5
G174	Sprays	1	0.28
G175	Cans (beverage)	22	0.55
G176	Cans (food)	3	0.06
	Total	**5.01%**	**32.96 %**

Met-ocean data

Surface currents were obtained from the operational IBI (Iberian Biscay Irish) Ocean Analysis and Forecasting System, provided by the Copernicus Marine Environment Monitoring Service (CMEMS). The system is based on a NEMO model and forced with 3-hourly atmospheric fields from ECMWF (see (Sotillo et al., 2015) for details). The data is available at a 0.083° × 0.083° horizontal resolution using 50 vertical levels. Surface currents were extracted in the same horizontal grid at the nominal depth of 1 m.

For Set 2, simulations were driven by the one-hourly ERA5-U10-wind fields generated by the atmospheric IFS model of the European Center for Medium-Range Weather Forecast (ECMWF) (see (C3s, 2019) for details). ERA5 atmospheric reanalysis database covers the Earth on a 30 km horizontal grid using 137 vertical levels from the surface up to a height of 80 km and provides estimates of a large number of atmospheric, land and oceanic climate variables on a 0.3° × 0.3° grid, currently from 1979 to within 3 months of real time. Both hourly simulated winds and surface currents were extracted from 1998 to 2017 and coupled to the model.

Methods

The modelling methodology was underpinned on realistic descriptions of fishing-related FML sources defined in "*Fishing-related FML data"* Section. The availability of met-ocean long-term datasets allowed to apply the probabilistic Monte Carlo technique to consistently simulate particle trajectories throughout the year. A database of FML trajectories under different met-ocean conditions (scenarios) was achieved for each month. Monte Carlo is considered a useful approach to overcome the uncertainty of modelling complex situations where many random variables are involved; Monte Carlo technique can be applied for predicting potential pollution events (Abascal et al., 2010; Alves et al., 2014; Morell Villalonga et al., 2020), assessing beach litter presence (Martínez-Ribes et al., 2007; Schulz et al., 2019; Álvarez et al., 2020) or forecasting marine litter transport (Quan Luna et al., 2012; Liubartseva et al., 2018a). Abascal et al. (2010) revealed that 200 scenarios can be suitable to characterize the seasonally particle behaviour within the BoB. Following this recommendation, in this analysis, 200 scenarios per month and 2400 in total were randomly selected. The number of particles per grid was estimated for the set of all scenarios according to Eq. (1):

$$N(i,j,t) = \sum_{s=1}^{S} \sum_{t=1}^{T} n(i,j,t) \qquad (1)$$

where S is the number of scenarios, t is the time, T the simulation period and i,j the grid nodes.

Windage assignment for Set 1 and Set 2 was Cd = 0 % and Cd = 4 %, respectively. Both simulation sets were conducted using the transport module of the TESEO model (Abascal et al., 2007; Abascal et al., 2017a; Abascal et al., 2017b).

TESEO is a 3D numerical model conceived to simulate the transport and degradation of hydrocarbons, as well as the drift of floating objects and people in marine environments, on both regional and local scale. The transport module allows including environmental conditions -wind, waves and currents-to compute particle trajectories. The transport model has been calibrated and validated by comparing virtual particle trajectories to observed surface drifter trajectories at regional and local scale (Abascal et al., 2009; Abascal et al., 2017a; Abascal et al., 2017b). Recently, TESEO has been also successfully applied to marine litter transport studies (Mazarrasa et al., 2019; Núñez et al., 2019). Pretests were performed to establish the numerical settings of the simulations in order to balance the number of particles and the time step for computing their transport. Finally, 30,000 particles were released per month - 20,100 and 9900 for Set 1 and Set 2 accordingly - ensuring a good performance of the model without compromising the computing time and the results. Pathways were calculated from the release location (Fig. 3) until the end of the simulation, allowing the position to be described in detail at temporal and spatial scale. Fishing-related FML items were treated as buoyant particles and advected by 2D surface ocean current fields. Wave effects were omitted.

The domain was divided into a regularly spaced grid of 61 × 133 elements and 0.08° × 0.08° spatial resolution (Δx). A land-sea mask was embedded in the model to undertake the beaching assessment. For each particle, the displacement was integrated with the time step (Δt) of 1800s, thus the particles will not displace more than one grid in one time step (Price et al., 2004; Abascal et al., 2010). As mentioned, 200 scenarios per month and 2400 in total were randomly selected. For each scenario, particles were initialized as an instantaneous release and run for 90 days as suggested as valid for basin scale by (Mansui et al., 2020). A turbulent diffusion coefficient of 1 m 2s–1 was set according to previously FML modelling studies carried within the BoB (Pereiro et al., 2019) to account for sub grid dispersion. Finally, the position of each particle along its trajectory and the density of particles per cell was saved every 12 h (Table 5.9).

Particles stranded in the limit of the coastline cells bordering land were treated as beached litter. Particles escaped from geographical limits of the study area - northern, southern and western boundary - were considered in order to quantify the accumulation rate of particles escaped. Once beached or escaped, particles were removed from further model computational steps.

The mean accumulation rate of beached, floating, and escaped particles was calculated by averaging the accumulation rate for each time step throughout the year during the integration time. The evolution of the accumulation rate was calculated based on a weekly assessment. The spatial accumulation was calculated by the end of the simulation (90 days-period). Concentrations in the MPAs were quantified as the ratio between the number of particles accumulated by the end of the simulation (n) and the MPA surface area (km2). MPAs areas with spatial scale smaller than the grid were not included in the analysis.

Table 5.9. Simulation, release, and physical parameter values corresponding to simulation Set 1 and Set 2.

	Simulation parameters			**Release parameters**		**Physical parameters**	
	Number of particles per month (total)	Integration time	Time step	Release locations	Release time	Turbulent diffusion coefficient	Windage coefficient
Set 1	20,100 (241,200)	90 days	1,800 s	Proportional to monthly fishing effort	Randomly selected by month	1 m2 /s	0%
Set 2	9,900 (1128,800)						4 %

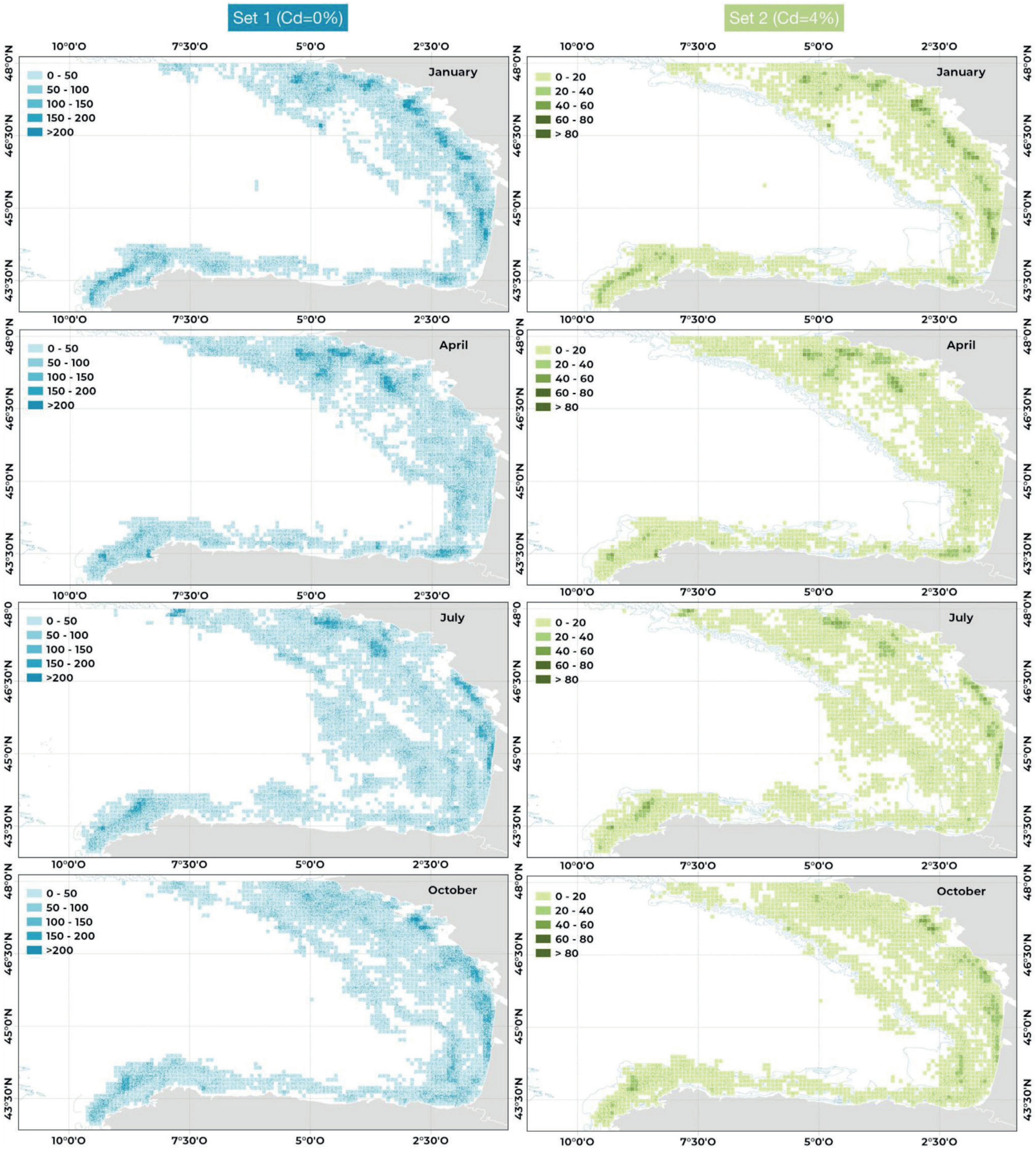


Fig. 5.19. Release locations for Set 1 (blue) and for Set 2 (green) initialized in January, April, July and October. Additional figures for the remaining months are available in Supplementary Figure 5.11 and 5.12.

RESULTS

Temporal FML accumulation

Mean accumulation rate

Over 24 % of particles from Set 1 and 80 % from Set 2 beached at the end of the simulations (Fig 5.20). For Set 2, beaching increased rapidly during the first-time steps and gradually levelled for the second half of the simulation period. At the end of the simulation, more than 55 % of particles from Set 1 remained floating at sea surface and less than 1 % from Set 2 still floated. No significant differences were observed amongst Set 1 (21 %) and Set 2 (19 %) in terms of accumulation of particles escaping the area. Particles from Set 1 were most likely to escape through the northern boundary (14 %) comparing to Set 2 (10 %); only 2 % and 3 % of particles ended up at the western boundary for Set 1 and Set 2 respectively. Less than 5 % of particles escaped from the BoB through the southern boundary for both sets.

Accumulation rate progress

High temporal variability was observed over the year on surface surface and coastal accumulation for both sets (Fig 5.21).

The accumulation rate for floating particles from Set 1 ranged from 85 to 89 % (minimum-maximum values respectively) after one week to 44–59 % by the end of the simulation period. In contrast, surface accumulation for particles from Set 2 varied from 48 - 57 % to 0.2–1.4 % for the same period. The most significant decrease for both cases occurred during summer.

Beached particles from Set 2 increased to 65–80 % after one month of simulation to subsequently stabilized over 80 % till the end of the simulation period. Beaching for particles from Set 1 increased from 6 to 10 % after one-week simulation to 20–35.5 % by the end of the simulation. Beaching was also significant during summer.

For both sets, particles escaped more easily through the northern boundary comparing to the other boundaries. In autumn and winter, between 3 and 10 % of particles from Set 2 and 2–4 % of particle from Set 1 escaped during the first week of simulation; the accumulation rate hardly increased in both cases above 4–21 % by the end of the simulation. It was observed that few particles escaped through the western boundary: only 0.15–3.3 % of particles escaped for Set 1 and 0.4 %–6.12 % for Set 2. The particles escaped mainly in winter and during the first weeks of the simulations. Similar rate of particles ranging from 1.8 to 9 % escaped through the southern boundary under the different windage conditions. In this case, particles mostly escaped by end of spring and during summer.

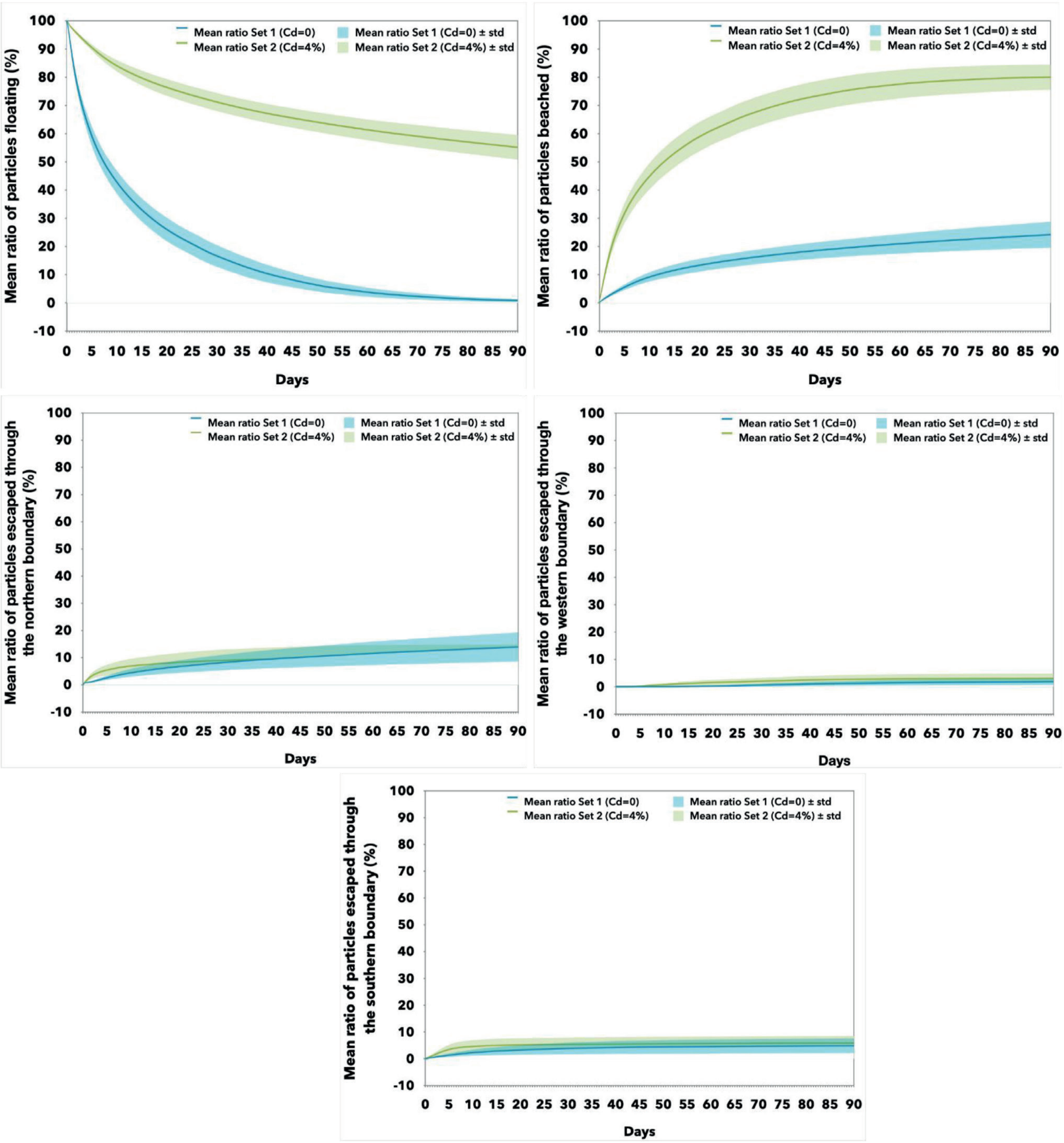


Fig. 5.20. Mean accumulation ratio for Set 1 (blue) and Set 2 (green) of floating, beached and escaped particles through the three open boundaries. The average was calculated per each time step of the integration time throughout the year.

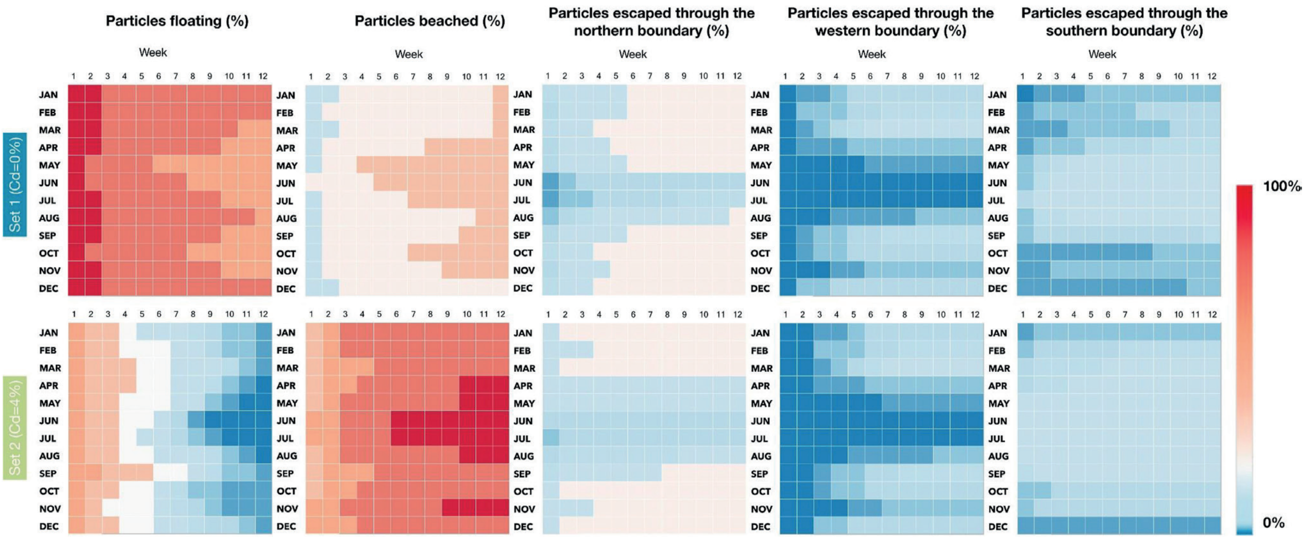


Fig. 5.21. Annual accumulation rate progress for Set 1 (figure above) and Set 2 (figure below) of floating, beached and escaped particles through the three open boundaries. The assessment of the accumulation rate was calculated every week during the simulation period (90 days).

Spatial FML accumulation

A large number of particles from Set 1 continued floating in the BoB at the end of the simulations. However, particle from Set 2 were mainly transported by the wind towards the coast and finally beached (Fig 5.22). The spatial distributions of modelled particles showed remarkable seasonality. Particles from Set 1 were more prone to remain in the sea surface in autumn and winter. Particles tended to accumulate towards the western Spanish coast (between 8°W 9°W) and on the eastern Spanish coast (between 2°W 4°W) throughout the spring. The eastern accumulation region gradually decreased in autumn though higher accumulation on the western coast was still present. Whether autumn and summer, accumulation both in the coastal area and sea surface scarced on the Spanish central zone (between 5°W 7°W). For Set 2, accumulation on the sea surface was almost non-existent. However, the strong influence of the windage on the coastal accumulation was clearly evidenced along the French shoreline, resulting in a larger particle concentration throughout the year comparing to the Spanish coastline. Autumn and winter fostered particle accumulation mainly in the French coastal areas from 44°N up to 47°N. However, during spring and summer particles also beached in the French southerly coast (between 43°N 44°N) and in the Basque coast (between 2°N 3°N). Isolated hotspots showed up on the eastern Spanish coast during this period.

FML concentrations in MPA

MPAs over the continental shelf experienced higher concentration comparing to those sited over the abyssal plain (Fig 5.23). The most frequent range of concentration for Set 1 and Set 2 was 1–50 particles/km2. The mean particle concentration per MPA for Set 1 and Set 2 was 23.12 particles/km2 and 28.29 particles/km2, respectively. For Set 1, three of the five MPAs experiencing the highest mean particle concentration were located in France (Île d'Yeu - 216.77 particles/km2, Île de Groix - 78.55 particles/km2, and Iroise - 74.33 particles/km2) and two in Spain (Espacio Marino de la Ría de Mundaka – 75.60 particles/km2 and Espacio marino de la Costa da Morte - 48.82 particles/km2); For Set 2, four of the five MPAs experiencing the highest mean particle concentration were located in France (Estuaire de la Bidassoa et baie de Fontarabie - 125.83 particles/km2, Île d'Yeu - 124.65 particles/km2, Baie de Quiberon - 117.70 particles/km2, and Île de Groix - 93.81 particles/km2) and one in Spain (Espacio marino de la Ría de Mundaka-Cabo de Ogoño - 101.40 particles/km2). French and Spanish MPAs experienced higher concentration for both sets mainly by the end of summer and during autumn.

DISCUSSION

Modelling approaches are crucial to accurately predict where marine litter will converge in the BoB, described as a regional hotspot of FML. Since information on the origins and the contribution of windage effect on FML circulation are not well known in the area, a better understanding of the relative importance of both parameters is needed. The results of this study provide initial insights of the influence of windage effect on simulated particles allocated as fishing related items and the estimation of their distribution patterns and concentrations in MPAs within the BoB.

Assumptions on fishing sources

Contributions to measure the importance of sea-based sources in a given region, particularly fisheries, can be considered relevant since a growing number of studies link marine litter presence to areas of high fishing activity (Pham et al., 2014; Unger and Harrison, 2016; Richardson et al., 2019). This study combines fishing FML data from surveys with modelling approaches to explore for the first time the behaviour of fishing-related items within the BoB. However, there are two assumptions in the allocation of fishing sources that are important to consider. First, the existing data concerning the origin of FML are not evenly collected throughout the BoB. FML samples derive from litter windrows located in the south-eastern BoB (Ruiz et al., 2020). Sampling elsewhere is substantially more sparse and mainly limited to visual observations.

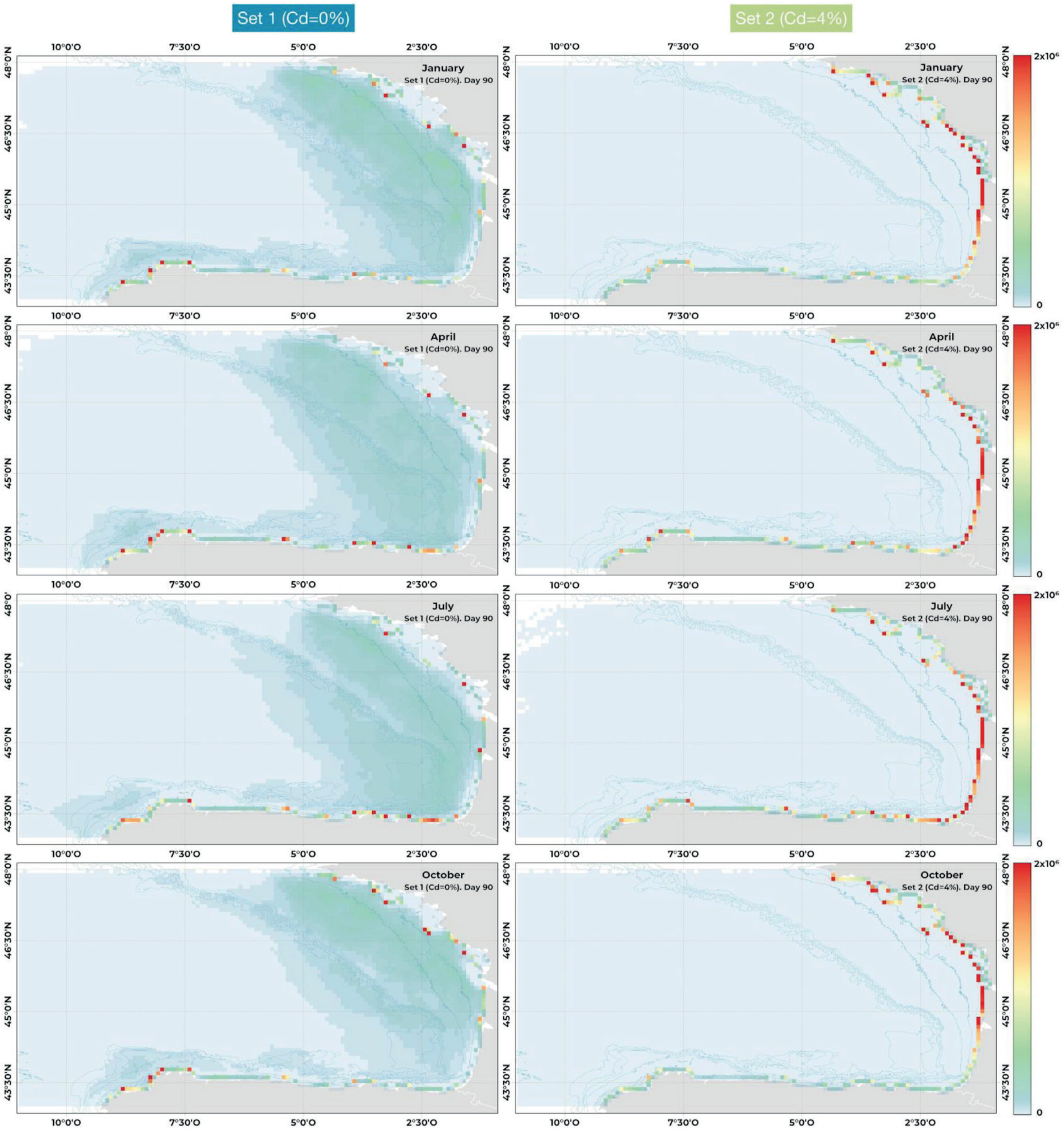


Fig. 5.22. Spatial particle accumulation for Set 1 (left) and Set 2 (right) after 90 days of simulation. The figures show the particle accumulation for the releasing initialized in January, April, July and October. Additional figures for the remaining months are available in Supplementary Figure 5.13 and 5.14.

Second, sampling activities in the litter windrows have limited temporal coverage. This hampers the interpretation of temporal trends in abundance and origins of fishing FML affected as well by seasonal changes in currents, winds, wave action, etc. Still, these data represent a potentially valuable information on fishing-related FML origins not available from any other source.

Windage parametrization and FML distribution

This study allowed for distribution of low (Set 1) and high windage parametrized simulations (Set 2) to be compared. Results are consistent with previous studies documented in literature, which highlight the significant impact of windage effect on FML transport and accumulation (Breivik et al., 2011; Maximenko et al., 2018; Ko et al., 2020). Simulations underlined an asymptotic behaviour of particle accumulation over the integration time, regardless the windage coefficient (Fig 5.21). At basin scale, a similar accumulation has been described for the Mediterranean Sea (Zambianchi et al., 2017). The mean rate of particles beached is far greater and occur faster for Set 2, particularly in summer (Fig 5.21, Fig 5.22). During this period, winds tend to have a marked north/north-eastward component resulting in strongly beaching for the French coast. Large surface accumulation rates are observed during winter for Set 2 (Fig 5.22). Furthermore, particles are more likely to remain floating and accumulate in the French shelf instead of becoming beached or escaped. In winter, currents induced by IPC may result in stronger particle transport and accumulation from the Spanish towards to the French shelf (Fig 5.23). Conversely, the circulation becomes weaker and equatorward from April to September. This flow can favour a higher retention mainly in the south-eastern continental shelf of the BoB, in line with results already described in the literature (Declerck et al., 2019; Pereiro et al., 2019). Results also showed that particles barely escape from the BoB and the direct effect of wind does not play a major role in this process. This agrees well with recently studies which stated that the BoB acts as trapping zone for FML, particularly for meso (5–25 mm) and macro (25–1000 mm) litter items (Rodríguez-Díaz et al., 2020). Particles mainly scape throughout the northern boundary mainly due to the effect of surface currents. During summer, the prevalence of north-westerlies winds may result in low number of escaped particles, particularly for particles from Set 2 (Fig 5.21 and 5.22).

Model limitations

In addition to the assumptions concerning the temporal and spatial coverage of fishing sources, numerical simulations require simplifications of processes that influence their accuracy (van Sebille et al., 2018). In this study, once particles beached, it is assumed that it is its final destination. However, the state of particles at the

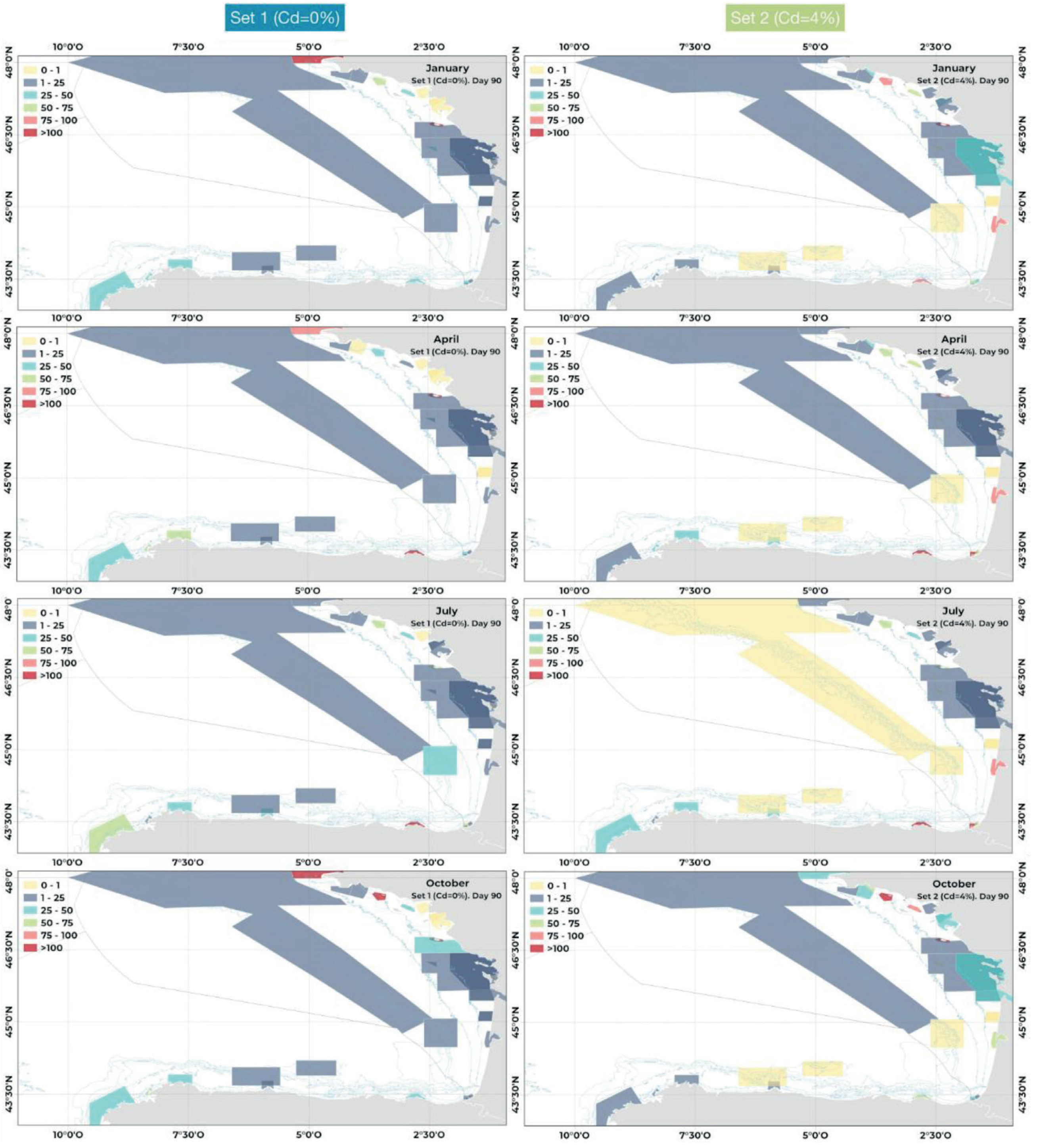


Fig. 5.23. Concentration within the MPAs for set 1 (left) and Set 2 (right) after 90 days of simulation. Concentrations in the MPAs (n/km2) were quantified as the ratio between particle accumulation by the end of the simulation and the MPA surface area. The figures show the particle concentrations for the releasing initialized in January, April, July and October. Additional figures for the remaining months are available in Supplementary Figure 5.15 and 5.16.

shoreline can vary between beached and re-floated episodes. Particle experiences different behaviour depending on complex physical processes but how they contribute to the final particle state is still unknown (Hardesty et al., 2016; Carlson et al., 2017; Utenhove, 2019). Furthermore, few studies on the coastal contribution to marine litter fragmentation and sinking have been carried out so far. Therefore, no interaction between the surface and seabed within the shoreline have been considered. Wind-induced mixing of water can distribute FML from the surface along the water column. This vertical mixing has been addressed in previously studies focus on microplastic distribution (Kukulka et al., 2012; Kooi et al., 2016; YanfangLi et al., 2020). Vertical mixing is not included in this study since the application of the model is limited to macro litter items with strong buoyancy.

Based on previous studies that show the relevance of the wind drift and surface currents in the transport of floating objects in the study site (Abascal et al., 2009), waves were omitted as forcing of the numerical model. Usually, wind and waves effects are considered together and represented by the windage coefficient (Abascal et al., 2009; Pereiro et al., 2018). However, this approach remains appropriate only while the waves are directly related and propagate in the same direction as the local wind. Therefore, more research would be required to incorporate the wave-induced Stokes drift into the numerical model and to consider the effect of the swell on FML transport.

Despite waves can induce the transport close to shore and play an important role in coastal areas and especially in beaches, including dynamics due to waves and the high-resolution process nearshore are beyond the scope of this paper.

Implications for MPAs management

The recently adopted EU Biodiversity Strategy sets the goal to improve and expand the coverage of European MPAs from 10 % to 30 % for 2030 (EEA, 2018; Agnesi et al., 2020). Such political commitments require well-managed MPAs to avoid the impact of marine pollution. Monitoring tools and numerical approaches become crucial to determine the environmental status of the MPAs and to design effective measures to reduce litter input. In this study, concentrations obtained both for Set 1 (mean 23.1 particles/km2 - max 125.8 particles/km2) and Set 2 (mean 28.3 particles/km2 - max 270.81 particles/km2) showed lower values compared with previous data reported from Mediterranean MPAs. Average abundance from seasonal surveys performed by (Ruiz-Orejón et al., 2019) in Menorca Channel MPA (Balearic Islands) ranged from 373 items/km2 to 1315 items/km2 throughout the year. Though, these results account for the entire fraction of marine litter sampled and they are not limited exclusively to fishing-related items.

Likewise, French MPAs located in the continental shelf of the BoB experienced higher FML concentrations despite windage conditions. Vessel-based activities and a high proportion of the MPAs documented in this study are located in the same geographical area, mainly in the continental shelf. Since particles have been allocated based on the fishing effort, the proximity of the release locations to the MPAs may influence the final FML destination and concentration. If the release take place offshore and far from the continental shelf, the transport and distribution occur more gradually, mainly for Set 1. This scenario gives a larger time window to stakeholders to act. However, the proximity to the release locations constitutes a threat to the MPAs, particularly for French ones, as it reduces the response time to critical pollution events.

The evidence of harm from marine litter to biota has been collected over the past years, underlying the negative impacts on marine organisms and habitats conservation. Entanglement, ingestion, the transport of microplastic or invasive species are major examples of the adverse consequences of marine litter exposure. The mobility of FML under the influence of currents and wind and, particularly, of highly buoyant items poses an elevated risk, especially for French MPAs, undermining ecosystem services provided by the MPAs and, consequently, bringing losses to economic French and Spanish sectors such tourism, fisheries and aquaculture.

Research conducted so far to assess the influence of MPAs in the society have highlighted their positive effects on human well-being (Rasheed, 2020; Garcia Rodrigues et al., 2021). Since MPAs outcomes are positive for the relationship between humans and the environment, stakeholders in the BoB should explore integrating study results on marine litter abundance and distribution to foster comprehensive measures and enhance the governability for a maximum well-being impact.

Regional and local management actions to address sea-based pollution are necessary to tackle the problem at source. A dedicated database to identify which derelict fishing gears are predominant in the study area coupled with interviews of fishers can help improve fishery management scheme and regulation. Assist in the selection of an appropriate disposal site or provide tools for fishers to underpin monitoring and/or control of their gear(s) increase the opportunity of the fishing sector to intervene on the prevention of gear loss and cut down fishing and shipping related litter presence in MPAs.

Recent transboundary initiatives implemented in the area such LIFE LEMA project (https://www.lifelema.eu/en/) or the innovative FML-TRACK service (https://fmltrack.rivagesprotech.fr/) acknowledge the need to extend solution-oriented tools to tackle FML in the BoB, ensuring in this way a more effective MPAs conservation. It has emerged clearly the importance of modelling to improve capabilities to prevent and remove FML underpinned by the availability of open and quality assured oceanographic products such as those provided by Copernicus Marine Environment Monitoring Service (CMEMS). Modelling assessments coupled with complementary videometry approaches, which monitor and estimate riverine litter quantities released into the coastal area, support decision-makers on FML management in the south-east of the BoB (LEMA, 2020; Delpey et al., 2021). Since the outcomes delivered by models and videometry provide near-real time FML abundances and predictions on transport and distribution of FML, they should be taken into consideration by the competent French and Spanish authorities for evaluating possible environmental consequences for MPAs in the case of intentional and unintentional marine litter releases.

Recommendations for future research

Research on marine litter behaviour in the BoB is still in its early stage. One of the greatest challenges is actually create new insights on FML circulation from fishing-related activities to prevent and mitigate its impact at basin scale. To address the gaps in the current knowledge, more observations of actual fishing FML abundances are needed. Besides, there is still much work to be done on explaining what kind of objects are released within the BoB since litter trajectories can be significantly altered by the wind conditions. Improved parameterizations of windage coefficient are crucial to better understand the modelled FML pathways and destiny. Despite a significant proportion of marine litter in the BoB may be sourced from the fishing sector, commercial and recreational shipping activities also contribute to marine litter in the area. Hence, shipping routes need to be included in future studies to give a full picture of the influence sea-based sources occurring on the BoB. The validation of computed particle trajectories and concentrations remains challenging due to the lack of observed data. Thus, furthercollection of field data and investment in FML monitoring are recommended. Long term, large spatial scale, standard and harmonised data are required to assess the performance of the results. Particle movement and distribution are more chaotic in coastal waters. This would need further investigation from Lagrangian analysis of highresolution current and wind data to accurately address beaching and refloating of litter processes. Using Lagrangian approaches to resolve the hydrodynamic connectivity in the BoB can provide also valuable information on the origin and age of the water masses within the MPAs to appropriately deal with the potential sources of FML at basin scale (van Sebille and et al., 2018). Lastly, efforts have been made over the last few years to confer the protected status of MPA to European areas of high ecological value, therefore, consistent data from monitoring enable also reasonable policy decisions for medium- and long-term strategies especially to those MPAs significantly impacted by FML.

CONCLUSIONS

Fishing sources have been considered in this study to assess FML circulation within the BoB under different windage conditions. Simulations allowed for studying the distribution patterns and concentrations of low and highly buoyant fishing-related items. Results demonstrate that windage effect shapes FML behaviour in the BoB and confirm the need to be incorporated in modelling simulations to fully understand FML transport and fate. The behavioral differences over spatial and temporal scale underline the high variability in particle accumulation and provide seasonal information to decision-makers on the likely fate of FML. Particular attention should be paid to the French coastline since high exposure to FML accumulation is expected mainly during summer season especially for highly buoyant items. Results lends weight to the argument that the BoB is an accumulation region for FML and strengthens the need to comply with prevention measures at source, particularly for fishing activities. Preventive and behaviour-changing measures become important in addressing fishing FML generation and disposal due to the combination of the geographical proximity between the area where fishing vessels operate, the coastal area and the MPAs. For highly buoyant items, mitigating measures should be rapid implemented to fit the limited time for intervention between FML realising and coastal and MPA arrival. Further simulations with more windage parametrization and experimental research (i.e: drifters) is recommended to provide new insights on FML behaviour and to validate the modelled results. Besides, monitoring efforts are required to provide the necessary information to implement and to assess the efficiency of specific measures for tackle FML in the BoB.

AUTHOR STATEMENT

Irene Ruiz: Data analysis, Investigation, Visualization, Writing- Original draft preparation Ana J. Abascal: Conceptualization, Methodology, Software, Writing- Reviewing & Editing Oihane C. Basurko: Conceptualization, Methodology, Writing- Reviewing & Editing, Supervision. Anna Rubio: Conceptualization, Methodology, Writing-Reviewing & Editing, Supervision.

ACKNOWLEDGEMENTS

This research has been partially funded through the EU's LIFE Program (LIFE LEMA project, grant agreement no. LIFE15 ENV/ES/000252), EU's H2020 Program (JERICO-S3 project, grant agreement No. 871153) and by the Spanish Ministry of Science and Innovation (OILHAZAR-D3D project, TRA2017-89164-R). This study has been conducted using E.U. Copernicus Marine Service Information. This is contribution number 1074 of AZTI, Marine Research, Basque Research and Technology Alliance (BRTA).2018).

References

Abascal, A., Castanedo, S., Gutierrez, A.D., Comerma, E., Medina, R., and Losada, I.J. (2007). Teseo, an operational system for simulating oil spills trajectories and fate processes. Proceedings of the International Offshore and Polar Engineering Conference, 1751-1758.

Abascal, A.J., Castanedo, S., Medina, R., and Liste, M. (2010). Analysis of the reliability of a statistical oil spill response model. Marine Pollution Bulletin 60, 2099-2110.

Abascal, A.J., Castanedo, S., Mendez, F.J., Medina, R., and Losada, I.J. (2009). Calibration of a Lagrangian Transport Model Using Drifting Buoys Deployed during the <i>Prestige</i> Oil Spill. Journal of Coastal Research 2009, 80-90, 11.

Abascal, A.J., Castanedo, S., Núñez, P., Mellor, A., Clements, A., Pérez, B., Cárdenas, M., Chiri, H., and Medina, R. (2017a). A high-resolution operational forecast system for oil spill response in Belfast Lough. Marine Pollution Bulletin 114, 302-314.

Abascal, A.J., Sanchez, J., Chiri, H., Ferrer, M.I., Cárdenas, M., Gallego, A., Castanedo, S., Medina, R., Alonso-Martirena, A., Berx, B., Turrell, W.R., and Hughes, S.L. (2017b). Operational oil spill trajectory modelling using HF radar currents: A northwest European continental shelf case study. Marine Pollution Bulletin 119, 336-350.

Addamo, A.M., Laroche, P., and Hanke, G. (2017). Top marine beach litter items in Europe. Publications Office of the European Union: Luxemburg.

Agnesi, S., Chaniotis, P., Korpinen, S., Snoj, L., Tunesi, L., and Reker, J. (2020). Spatial Analysis of Marine Protected Area Networks in Europe's Seas III.

Álvarez, S., Gestoso, I., Herrera, A., Riera, L., and Canning-Clode, J. (2020). A Comprehensive First Baseline for Marine Litter Characterization in the Madeira Archipelago (NE Atlantic). Water, Air, & Soil Pollution 231, 182.

Alves, T.M., Kokinou, E., and Zodiatis, G. (2014). A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins. Marine Pollution Bulletin 86, 443-457.

Barboza, L.G.A., Cózar, A., Gimenez, B.C., Barros, T.L., Kershaw, P.J., and Guilhermino, L. (2019). "Macroplastics pollution in the marine environment," in World seas: An environmental evaluation. Elsevier), 305-328.

Barnes, D.K.A., Morley, S., Bell, J., Brewin, P., Brigden, K., Collins, M., Glass, T., Goodall-Copestake, W., Henry, L., Laptikhovsky, V., Piechaud, N., Richardson, A., Rose, P., Sands, C., Schofield, A., Shreeve, R., Small, A., Stamford, T., and Taylor, B. (2018). Marine plastics threaten giant Atlantic Marine Protected Areas. Current Biology 28, R1137-R1138.

Betti, F., Bavestrello, G., Bo, M., Ravanetti, G., Enrichetti, F., Coppari, M., Cappanera, V., Venturini, S., and Cattaneo-Vietti, R. (2020). Evidences of fishing impact on the coastal gorgonian forests inside the Portofino MPA (NW Mediterranean Sea). Ocean & Coastal Management 187, 105105.

Borja, A., Amouroux, D., Anschutz, P., Gómez-Gesteira, M., Uyarra, M.C., and Valdés, L. (2019). "Chapter 5 - The Bay of Biscay," in World Seas: an Environmental Evaluation (Second Edition), ed. C. Sheppard. Academic Press), 113-152.

Boucher, J., and Friot, D. (2017). Primary microplastics in the oceans: a global evaluation of sources. Iucn Gland, Switzerland.

Breivik, Ø., Allen, A.A., Maisondieu, C., and Roth, J.C. 2011. Wind-induced drift of objects at sea: the leeway field method. Available: https://ui.adsabs.harvard.edu/abs/2011arXiv1111.0750B [Accessed November 01, 2011].

C3s (2019). ERA5: Fifth Generation of ECMWF Atmospheric Reanalyses of the Global Climate. [Online]. Available: https://cds.climate.copernicus.eu/cdsapp#!/home [Accessed 15 June 2019].

Carlson, D.F., Suaria, G., Aliani, S., Fredj, E., Fortibuoni, T., Griffa, A., Russo, A., and Melli, V. (2017). Combining Litter Observations with a Regional Ocean Model to Identify Sources and Sinks of Floating Debris in a Semi-enclosed Basin: The Adriatic Sea. Frontiers in Marine Science 4.

Consoli, P., Romeo, T., Angiolillo, M., Canese, S., Esposito, V., Salvati, E., Scotti, G., Andaloro, F., and Tunesi, L. (2019). Marine litter from fishery activities in the Western Mediterranean sea: The impact of entanglement on marine animal forests. Environmental Pollution 249, 472-481.

Cózar, A., Aliani, S., Basurko, O.C., Arias, M., Isobe, A., Topouzelis, K., Rubio, A., and Morales-Caselles, C. (2021). Marine Litter Windrows: A Strategic Target to Understand and Manage the Ocean Plastic Pollution. Frontiers in Marine Science 8.

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., and Duarte, C.M. (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences 111, 10239-10244.

Chassignet, E.P., Xu, X., and Zavala-Romero, O. (2021). Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From? Frontiers in Marine Science 8.

Day, J., Dudley, N., Hockings, M., Holmes, G., Laffoley, D.D.A., Stolton, S., and Wells, S.M. (2012). Guidelines for applying the IUCN protected area management categories to marine protected areas. IUCN.

Declerck, A., Delpey, M., Rubio, A., Ferrer, L., Basurko, O.C., Mader, J., and 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, 1-15.

Duhec, A.V., Jeanne, R.F., Maximenko, N., and Hafner, J. (2015). Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. Marine Pollution Bulletin 96, 76-86.

Eea (2018). Marine protected areas [Online]. Available: https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-protected-areas [Accessed March 2021].

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., and Reisser, J. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLOS ONE 9, e111913.

Fernandes, J.A., Granado, I., Murua, H., Arrizabalaga, H., Zarauz, L., Mugerza, E., Arregi, L., Galparsoro, I., Murua, J., and Iriondo, A. (2019). Bay of Biscay VMS/logbook comparison (FAO Subarea 27.8). Global Atlas of AIS-based fishing activity, 43.

Fossi, M.C., and Panti, C. (2020). "The Impact of Marine Litter in Marine Protected Areas (MPAs) in the Mediterranean Sea: How Can We Protect MPAs?," in Mare Plasticum - The Plastic Sea: Combatting Plastic Pollution Through Science and Art, eds. M. Streit-Bianchi, M. Cimadevila & W. Trettnak. (Cham: Springer International Publishing), 117-128.

Gago, J. (2014). Characteristics (abundance, type and origin) of beach litter on the Galician coast (NW Spain) from 2001 to 2010. Scientia Marina 78, 1-10.

Galgani, F., Hanke, G., and Maes, T. (2015). "Global Distribution, Composition and Abundance of Marine Litter," in Marine Anthropogenic Litter, eds. M. Bergmann, L. Gutow & M. Klages. (Cham: Springer International Publishing), 29-56.

Garcia Rodrigues, J., Villasante, S., and Sousa Pinto, I. (2021). Non-material nature's contributions to people from a marine protected area support multiple dimensions of human well-being. Sustainability Science.

Gilman, E., Musyl, M., Suuronen, P., Chaloupka, M., Gorgin, S., Wilson, J., and Kuczenski, B. (2021). Highest risk abandoned, lost and discarded fishing gear. Scientific Reports 11, 1-11.

Hardesty, B.D., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., Van Sebille, E., Vethaak, A.D., and Wilcox, C. (2017). Using Numerical Model Simulations to Improve the Understanding of Micro-plastic Distribution and Pathways in the Marine Environment. Frontiers in Marine Science 4.

Hardesty, D., Wilcox, C., and Lebreton, L. (2016). "Modelling and monitoring marine litter movement, transport and accumulation", in: For United Nations Environment Programme.).

Ices (2016). " Bay of Biscay and the Iberian Coast Ecoregion". ICES Ecosystem Overviews).

Jalón-Rojas, I., Wang, X.H., and Fredj, E. (2019). A 3D numerical model to Track Marine Plastic Debris (TrackMPD): Sensitivity of microplastic trajectories and fates to particle dynamical properties and physical processes. Marine Pollution Bulletin 141, 256-272.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. (2015). Plastic waste inputs from land into the ocean. Science 347, 768-771.

Kershaw, P., Carney Almroth, B., Villarrubia-Gómez, P., Koelmans, A., and Gouin, T. (2020). Proceedings of the GESAMP International Workshop on assessing the risks associated with plastics and microplastics in the marine environment.

Kershaw, P., Turra, A., and Galgani, F. (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. GESAMP reports and studies.

Ko, C.-Y., Hsin, Y.-C., and Jeng, M.-S. (2020). Global distribution and cleanup opportunities for macro ocean litter: a quarter century of accumulation dynamics under windage effects. Environmental Research Letters 15, 104063.

Kooi, M., Reisser, J., Slat, B., Ferrari, F.F., Schmid, M.S., Cunsolo, S., Brambini, R., Noble, K., Sirks, L.-A., Linders, T.E.W., Schoeneich-Argent, R.I., and Koelmans, A.A. (2016). The effect of particle properties on the depth profile of buoyant plastics in the ocean. Scientific Reports 6, 33882.

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. Geophysical Research Letters 39.

La Beur, L., Henry, L.-A., Kazanidis, G., Hennige, S., Mcdonald, A., Shaver, M.P., and Roberts, J.M. (2019). Baseline Assessment of Marine Litter and Microplastic Ingestion by Cold-Water Coral Reef Benthos at the East Mingulay Marine Protected Area (Sea of the Hebrides, Western Scotland). Frontiers in Marine Science 6.

Lavin, A., Valdés, L., Sanchez, F., Abaunza, P., Forest, A., Boucher, J., Lazure, P., and Jegou, A.-M. (2006). The Bay of Biscay: the encountering of the Ocean and the Shelf (18b, E). Combridge, MA, Harvard University Press.

Lebreton, L.C.M., Greer, S.D., and Borrero, J.C. (2012). Numerical modelling of floating debris in the world's oceans. Marine Pollution Bulletin 64, 653-661.

Lema, L. (2020). "LIFE LEMA's TECHNICAL SYNTHESIS REPORT", (ed.) Https://Www.Lifelema.Eu/Wp-Content/Uploads/2020/03/Life_Lema_Final_Technical_Report_V10-1_Compressed.Pdf.).

Li, W.C., Tse, H.F., and Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of The Total Environment 566-567, 333-349.

Liubartseva, S., Coppini, G., and Lecci, R. (2019). Are Mediterranean Marine Protected Areas sheltered from plastic pollution? Marine Pollution Bulletin 140, 579-587.

Liubartseva, S., Coppini, G., Lecci, R., and Clementi, E. (2018a). "Stochastic Lagrangian modeling the plastic marine debris in the Mediterranean Sea".).

Liubartseva, S., Coppini, G., Lecci, R., and Clementi, E. (2018b). Tracking plastics in the Mediterranean: 2D Lagrangian model. Marine Pollution Bulletin 129, 151-162.

Liubartseva, S., Coppini, G., Lecci, R., and Creti, S. (2016). Regional approach to modeling the transport of floating plastic debris in the Adriatic Sea. Marine Pollution Bulletin 103, 115-127.

Luna-Jorquera, G., Thiel, M., Portflitt-Toro, M., and Dewitte, B. (2019). Marine protected areas invaded by floating anthropogenic litter: An example from the South Pacific. Aquatic Conservation: Marine and Freshwater Ecosystems 29, 245-259.

Macfadyen, G., Huntington, T., and Cappell, R. (2009). Abandoned, lost or otherwise discarded fishing gear.

Macias, D., Cózar, A., Garcia-Gorriz, E., González-Fernández, D., and Stips, A. (2019). Surface water circulation develops seasonally changing patterns of floating litter accumulation in the Mediterranean Sea. A modelling approach. Marine Pollution Bulletin 149, 110619.

Mansui, J., Darmon, G., Ballerini, T., Van Canneyt, O., Ourmieres, Y., and Miaud, C. (2020). Predicting marine litter accumulation patterns in the Mediterranean basin: Spatio-temporal variability and comparison with empirical data. Progress in Oceanography 182, 102268.

Martínez-Ribes, L., Basterretxea, G., Palmer, M., and Tintoré, J. (2007). Origin and abundance of beach debris in the Balearic Islands. Scientia Marina 71, 305-314.

Maximenko, N., Corradi, P., Law, K.L., Van Sebille, E., Garaba, S.P., Lampitt, R.S., Galgani, F., Martinez-Vicente, V., Goddijn-Murphy, L., Veiga, J.M., Thompson, R.C., Maes, C., Moller, D., Löscher, C.R., Addamo, A.M., Lamson, M.R., Centurioni, L.R., Posth, N.R., Lumpkin, R., Vinci, M., Martins, A.M., Pieper, C.D., Isobe, A., Hanke, G., Edwards, M., Chubarenko, I.P., Rodriguez, E., Aliani, S., Arias, M., Asner, G.P., Brosich, A., Carlton, J.T., Chao, Y., Cook, A.-M., Cundy, A.B., Galloway, T.S., Giorgetti, A., Goni, G.J., Guichoux, Y., Haram, L.E., Hardesty, B.D., Holdsworth, N., Lebreton, L., Leslie, H.A., Macadam-Somer, I., Mace, T., Manuel, M., Marsh, R., Martinez, E., Mayor, D.J., Le Moigne, M., Molina Jack, M.E., Mowlem, M.C., Obbard, R.W., Pabortsava, K., Robberson, B., Rotaru, A.-E., Ruiz, G.M., Spedicato, M.T., Thiel, M., Turra, A., and Wilcox, C. (2019). Toward the Integrated Marine Debris Observing System. Frontiers in Marine Science 6.

Maximenko, N., Hafner, J., Kamachi, M., and Macfadyen, A. (2018). Numerical simulations of debris drift from the Great Japan Tsunami of 2011 and their verification with observational reports. Mar. Pollut. Bull. 132, 5.

Mazarrasa, I., Puente, A., Núñez, P., García, A., Abascal, A.J., and Juanes, J.A. (2019). Assessing the risk of marine litter accumulation in estuarine habitats. Marine Pollution Bulletin 144, 117-128.

Miladinova, S., Macias, D., Stips, A., and Garcia-Gorriz, E. (2020). Identifying distribution and accumulation patterns of floating marine debris in the Black Sea. Marine Pollution Bulletin 153, 110964.

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S., Basurko, O.C., Mallos, N., Lebreton, L., Echevarría, F., Van Emmerik, T., Duarte, C.M., Gálvez, J.A., Van Sebille, E., Galgani, F., García, C.M., Ross, P.S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., and Cózar, A. (2021). An inshore–offshore sorting system revealed from global classification of ocean litter. Nature Sustainability 4, 484-493.

Morell Villalonga, M., Espino Infantes, M., Grifoll Colls, M., and Mestres Ridge, M. (2020). Environmental Management System for the Analysis of Oil Spill Risk Using Probabilistic Simulations. Application at Tarragona Monobuoy. Journal of Marine Science and Engineering 8, 277.

Nelms, S.E., Eyles, L., Godley, B.J., Richardson, P.B., Selley, H., Solandt, J.-L., and Witt, M.J. (2020). Investigating the distribution and regional occurrence of anthropogenic litter in English marine protected areas using 25 years of citizen-science beach clean data. Environmental Pollution 263, 114365.

Neumann, D., Callies, U., and Matthies, M. (2014). Marine litter ensemble transport simulations in the southern North Sea. Mar. Pollut. Bull. 86, 219.

Noaa (2016). "Modeling Oceanic Transport of Floating Marine Debris". National Oceanic and Atmospheric Administration Marine Debris Program).

Núñez, P., García, A., Mazarrasa, I., Juanes, J.A., Abascal, A.J., Méndez, F., Castanedo, S., and Medina, R. (2019). A methodology to assess the probability of marine litter accumulation in estuaries. Marine Pollution Bulletin 144, 309-324.

Onink, V., Jongedijk, C.E., Hoffman, M.J., Van Sebille, E., and Laufkötter, C. (2021). Global simulations of marine plastic transport show plastic trapping in coastal zones. Environmental Research Letters 16, 064053.

Ospar (2020). “OSPAR scoping study on best practices for the design and recycling of fishing gear as a means to reduce the quantities of fishing gear found as marine litter in the North-East Atlantic”. (London, UK: OSPAR Comission).

Pawar, P., Shirgaonkar, S., and Affiliations, R. (2016). Plastic marine debris: Sources, distribution and impacts on coastal and ocean biodiversity. PENCIL Publication of Biological Sciences (OCEANOGRAPHY). 3(1): 40-54. (ISSN: 2408-5561). 3, 40-54.

Pereiro, D., Souto, C., and Gago, J. (2018). Calibration of a marine floating litter transport model. Journal of Operational Oceanography 11, 125-133.

Pereiro, D., Souto, C., and Gago, J. (2019). Dynamics of floating marine debris in the northern Iberian waters: A model approach. Journal of Sea Research 144, 57-66.

Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., Canals, M., Company, J.B., Davies, J., Duineveld, G., Galgani, F., Howell, K.L., Huvenne, V.a.I., Isidro, E., Jones, D.O.B., Lastras, G., Morato, T., Gomes-Pereira, J.N., Purser, A., Stewart, H., Tojeira, I., Tubau, X., Van Rooij, D., and Tyler, P.A. (2014). Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins. PLOS ONE 9, e95839.

Politikos, D.V., Tsiaras, K., Papatheodorou, G., and Anastasopoulou, A. (2020). Modeling of floating marine litter originated from the Eastern Ionian Sea: Transport, residence time and connectivity. Marine Pollution Bulletin 150, 110727.

Price, J., Johnson, W., Ji, Z.-G., Marshall, C., and Rainey, G. (2004). Sensitivity testing for improved efficiency of a statistical oil-spill risk analysis model. Environmental Modelling and Software 19, 671-679.

Purba, N.P., Faizal, I., Abimanyu, A., Zenyda, K.S., Jaelani, A., Indriawan, D., Priadhi, M.M., and Martasuganda, M.K. (2020). Vulnerability of Java Sea marine protected areas affected by marine debris. IOP Conference Series: Earth and Environmental Science 584, 012029.

Quan Luna, B., Cepeda, J.M., Stumpf, A., Westen, C.J., Malet, J.P., and Asch, T.W.J. (2012). Application of a Monte Carlo method for modeling debris flow run-out. 13718.

Rasheed, A.R. (2020). Marine protected areas and human well-being – A systematic review and recommendations. Ecosystem Services 41, 101048.

Rayon-Viña, F., Miralles, L., Gómez-Agenjo, M., Dopico, E., and Garcia-Vazquez, E. (2018). Marine litter in south Bay of Biscay: Local differences in beach littering are associated with citizen perception and awareness. Marine Pollution Bulletin 131, 727-735.

Richardson, K., Hardesty, B.D., and Wilcox, C. (2019). Estimates of fishing gear loss rates at a global scale: A literature review and meta-analysis. Fish and Fisheries 20, 1218-1231.

Rodríguez-Díaz, L., Gómez-Gesteira, J.L., Costoya, X., Gómez-Gesteira, M., and Gago, J. (2020). The Bay of Biscay as a trapping zone for exogenous plastics of different sizes. Journal of Sea Research 163, 101929.

Rubio, A., Hernández-Carrasco, I., Orfila, A., González, M., Reyes,E., Corgnati, L., Berta,M., Griffa, A., and Mader, J (2020). “A Lagrangian approach to monitor local particle retention conditions in coastal areas,” (ed.) C.M.S.O. State.).

Ruiz-Orejón, L.F., Mourre, B., Sardá, R., Tintoré, J., and Ramis-Pujol, J. (2019). Quarterly variability of floating plastic debris in the marine protected area of the Menorca Channel (Spain). Environmental Pollution 252, 1742-1754.

Ruiz, I., Basurko, O.C., Rubio, A., Delpey, M., Granado, I., Declerck, A., Mader, J., and Cózar, A. (2020). Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter. Frontiers in Marine Science 7.

Ryberg, M.W., Laurent, A., and Hauschild, M. (2018). Mapping of global plastics value chain and plastics losses to the environment: with a particular focus on marine environment.

Schulz, M., Walvoort, D.J.J., Barry, J., Fleet, D.M., and Van Loon, W.M.G.M. (2019). Baseline and power analyses for the assessment of beach litter reductions in the European OSPAR region. Environmental Pollution 248, 555-564.

Sherrington, C., Darrah, C., Hann, S., Cole, G., and Corbin, M. (2016). “Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment”. Eunomia).

Solabarrieta, L., Rubio, A., Castanedo, S., Medina, R., Charria, G., and Hernández, C. (2014). Surface water circulation patterns in the southeastern Bay of Biscay: New evidences from HF radar data. Continental Shelf Research 74, 60-76.

Sotillo, M.G., Cailleau, S., Lorente, P., Levier, B., Aznar, R., Reffray, G., Amo-Baladrón, A., Chanut, J., Benkiran, M., and Alvarez-Fanjul, E. (2015). The MyOcean IBI Ocean Forecast and Reanalysis Systems: operational products and roadmap to the future Copernicus Service. Journal of Operational Oceanography 8, 63-79.

Soto-Navarro, J., Jordá, G., Deudero, S., Alomar, C., Amores, Á., and Compa, M. (2020). 3D hotspots of marine litter in the Mediterranean: A modeling study. Marine Pollution Bulletin 155, 111159.

Stanev, E.V., and Ricker, M. (2019). The Fate of Marine Litter in Semi-Enclosed Seas: A Case Study of the Black Sea. Frontiers in Marine Science 6.

Taconet, M., Kroodsma, D., and Fernandes, J. (2019). “Global Atlas of AIS-based fishing activity”. (Rome: FAO).

Thushari, G.G.N., and Senevirathna, J.D.M. (2020). Plastic pollution in the marine environment. Heliyon 6, e04709.

Unep-Wcmc, I. (2019). “Protected Planet: the World Database on Protected Areas (WDPA), the Global Database on Protected Areas Management Effectiveness (GD-PAME)”. UNEP-WCMC and IUCN, Cambridge, UK. www. prote ctedp lanet. net).

Unep (2014). “Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry”.).

Unep (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change.

Unger, A., and Harrison, N. (2016). Fisheries as a source of marine debris on beaches in the United Kingdom. Marine Pollution Bulletin 107, 52-58.

Utenhove, E.V. (2019). “Modelling the transport and fate of buoyant macroplastics in coastal waters”).

Gennip, S.J.v., Dewitte, B., Garçon, V. et al. In search for the sources of plastic marine litter that contaminates the Easter Island Ecoregion. Sci Rep 9, 19662 (2019). https://doi.org/10.1038/s41598-019-56012-x

Van Sebille, E., Griffies, S.M., Abernathey, R., Adams, T.P., Berloff, P., Biastoch, A., Blanke, B., Chassignet, E.P., Cheng, Y., Cotter, C.J., Deleersnijder, E., Döös, K., Drake, H.F., Drijfhout, S., Gary, S.F., Heemink, A.W., Kjellsson, J., Koszalka, I.M., Lange, M., Lique, C., Macgilchrist, G.A., Marsh, R., Mayorga Adame, C.G., Mcadam, R., Nencioli, F., Paris, C.B., Piggott, M.D., Polton, J.A., Rühs, S., Shah, S.H.a.M., Thomas, M.D., Wang, J., Wolfram, P.J., Zanna, L., and Zika, J.D. (2018). Lagrangian ocean analysis: Fundamentals and practices. Ocean Modelling 121, 49-75.

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F., and Law, K.L. (2015). A global inventory of small floating plastic debris. Environmental Research Letters 10, 124006.

Veiga, J.M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Galgani, F., Thompson, R.C., Dagevos, J., and Gago, J. (2016). “Identifying sources of marine litter. MSFD GES TG Marine Litter Thematic Report”, in: JRC Technical Report. MSFD GES TG Marine Litter Thematic Report.EUR 28309.).

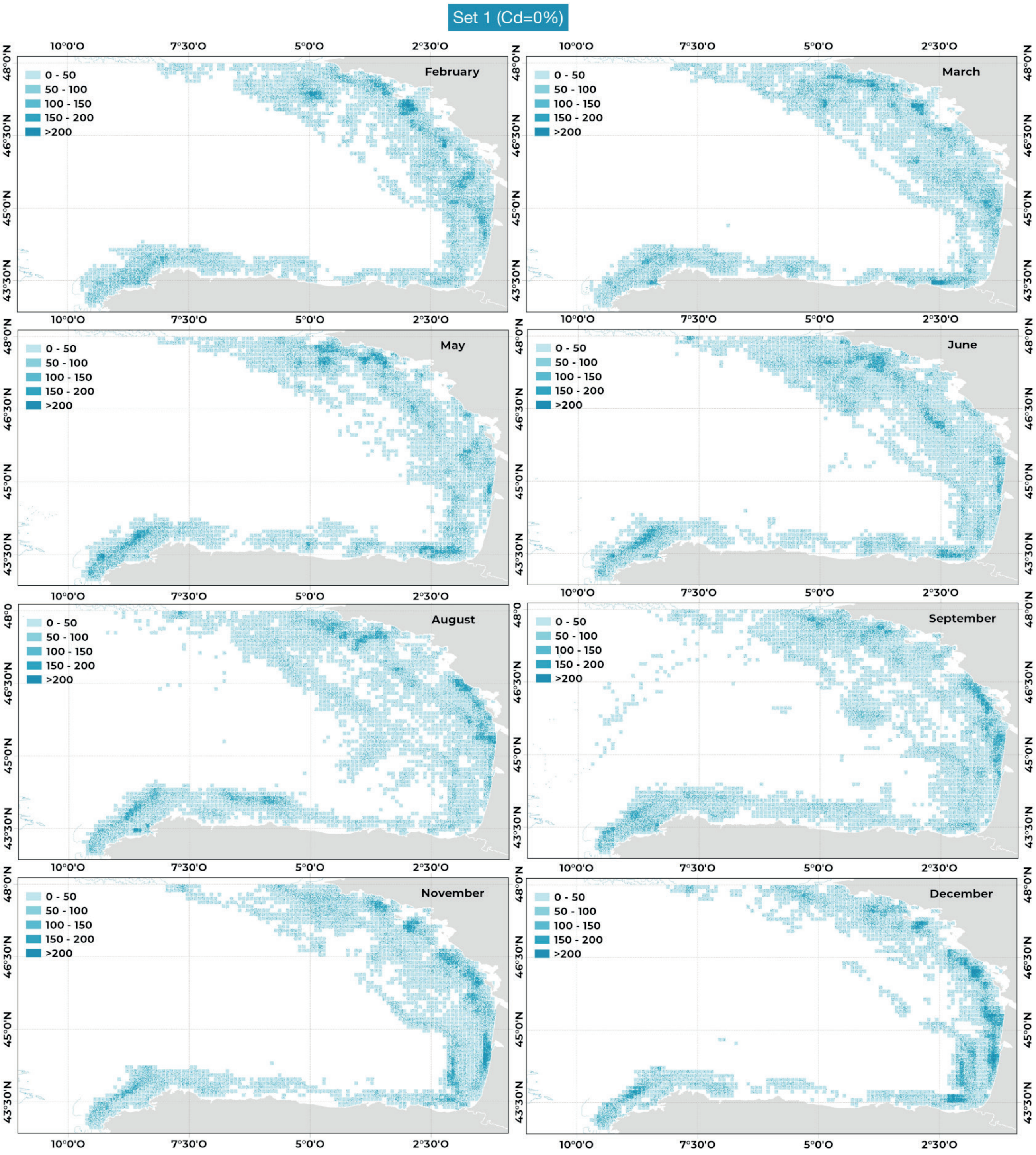
Yanfangli, Huazhang, and Chengtang (2020). A review of possible pathways of marine microplastics transport in the ocean. Anthropocene Coasts 3, 6-13.

Yoon, J.-H., Kawano, S., and Igawa, S. (2010). Modeling of marine litter drift and beaching in the Japan Sea. Mar. Pollut. Bull. 60, 448.

Zambianchi, E., Trani, M., and Falco, P. (2017). Lagrangian Transport of Marine Litter in the Mediterranean Sea. Frontiers in Environmental Science 5.

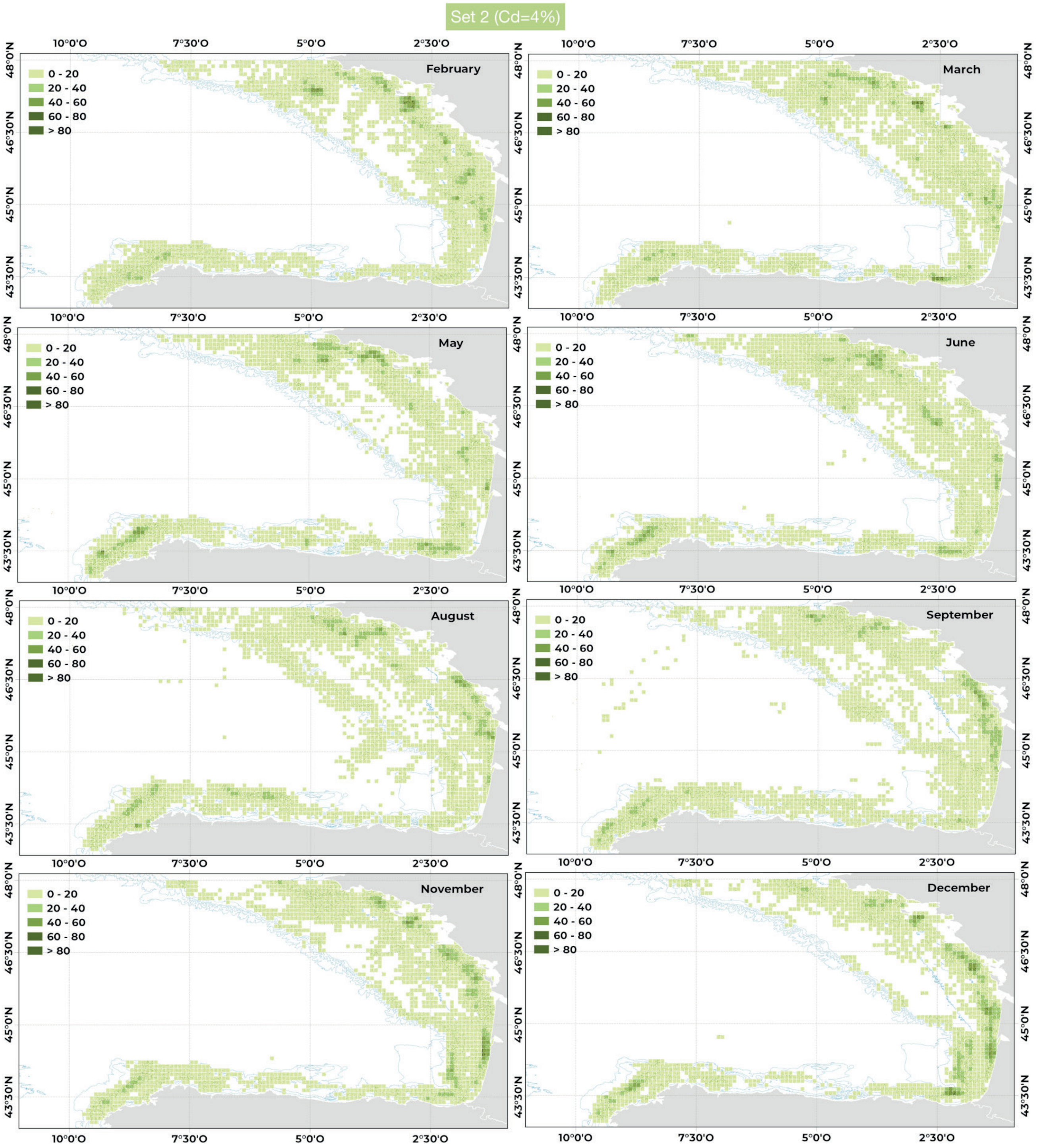
Supplementary material

Supplementary Figure 5.11



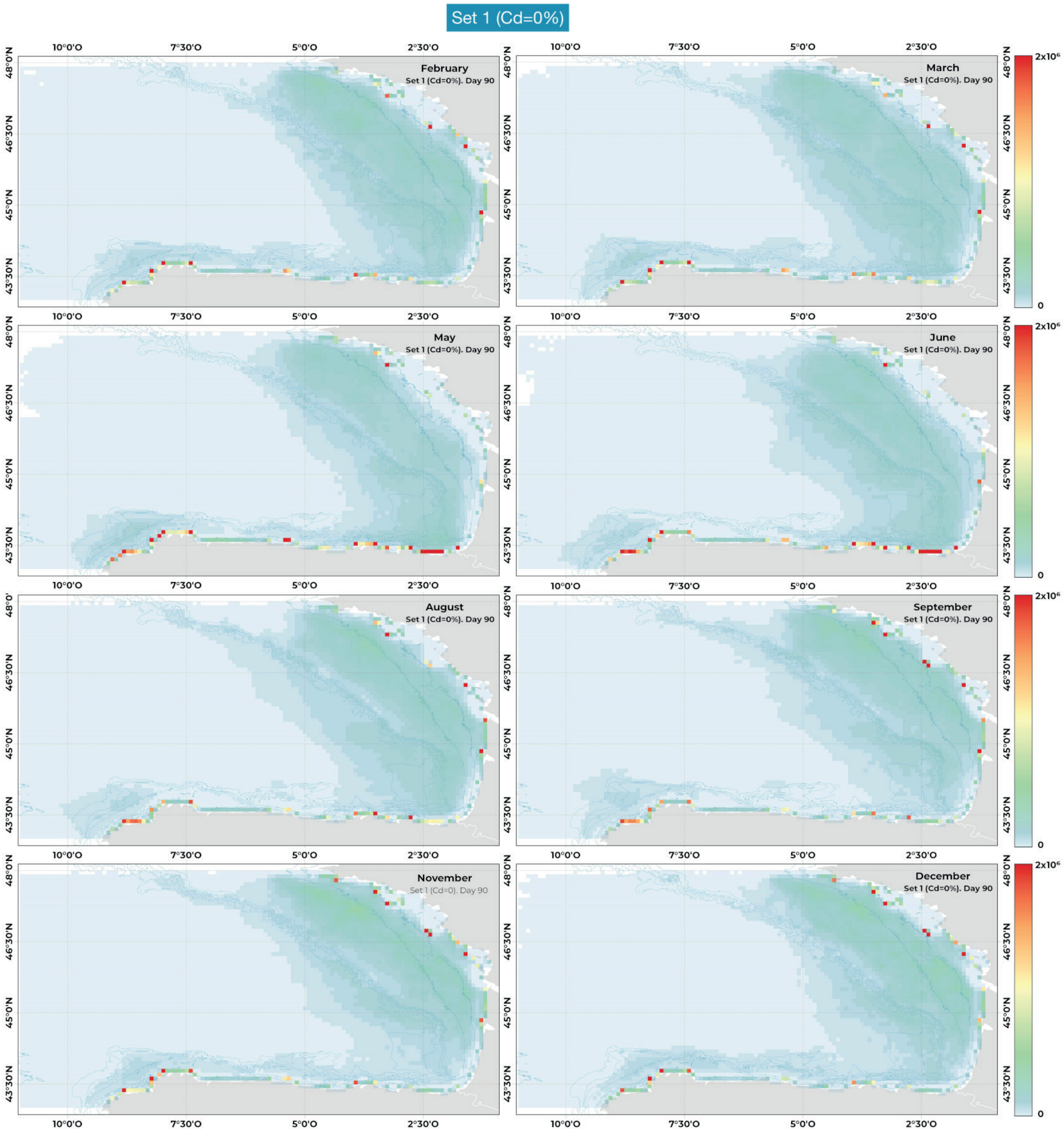
Supplementary Fig 5.11. Release locations for Set 1 initialized in February, March, May, June, August, September, November and December.

Supplementary Figure 5.12



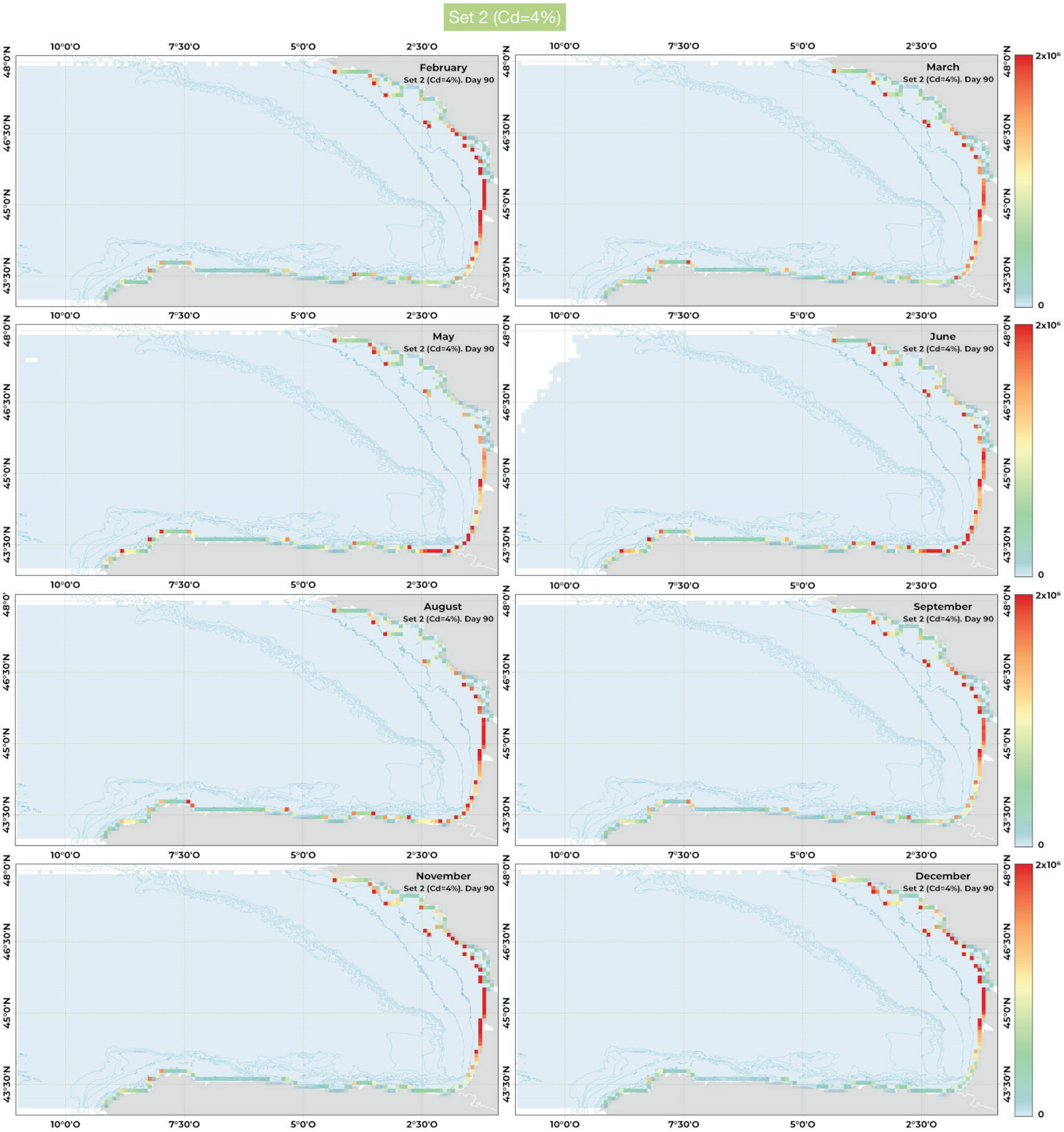
Supplementary Fig 5.12. Release locations for Set 2 initialized in February, March, May, June, August, September, November and December.

Supplementary Figure 5.13



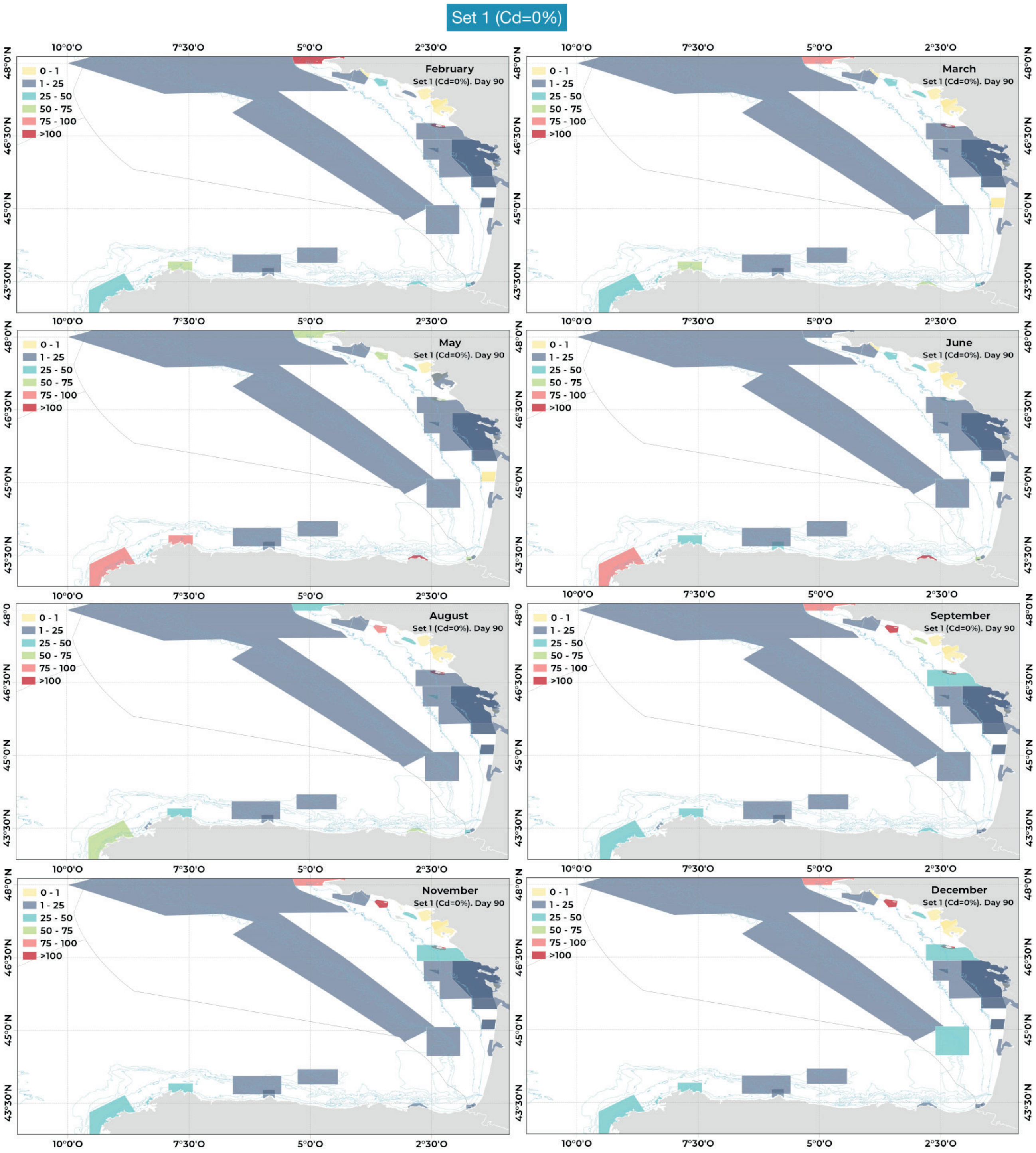
Supplementary Fig 5.13. Spatial particle accumulation for Set 1 after 90 days of simulation. The figures show the particle accumulation for the releasing initialized in February, March, May, June, August, September, November and December.

Supplementary Figure 5.14



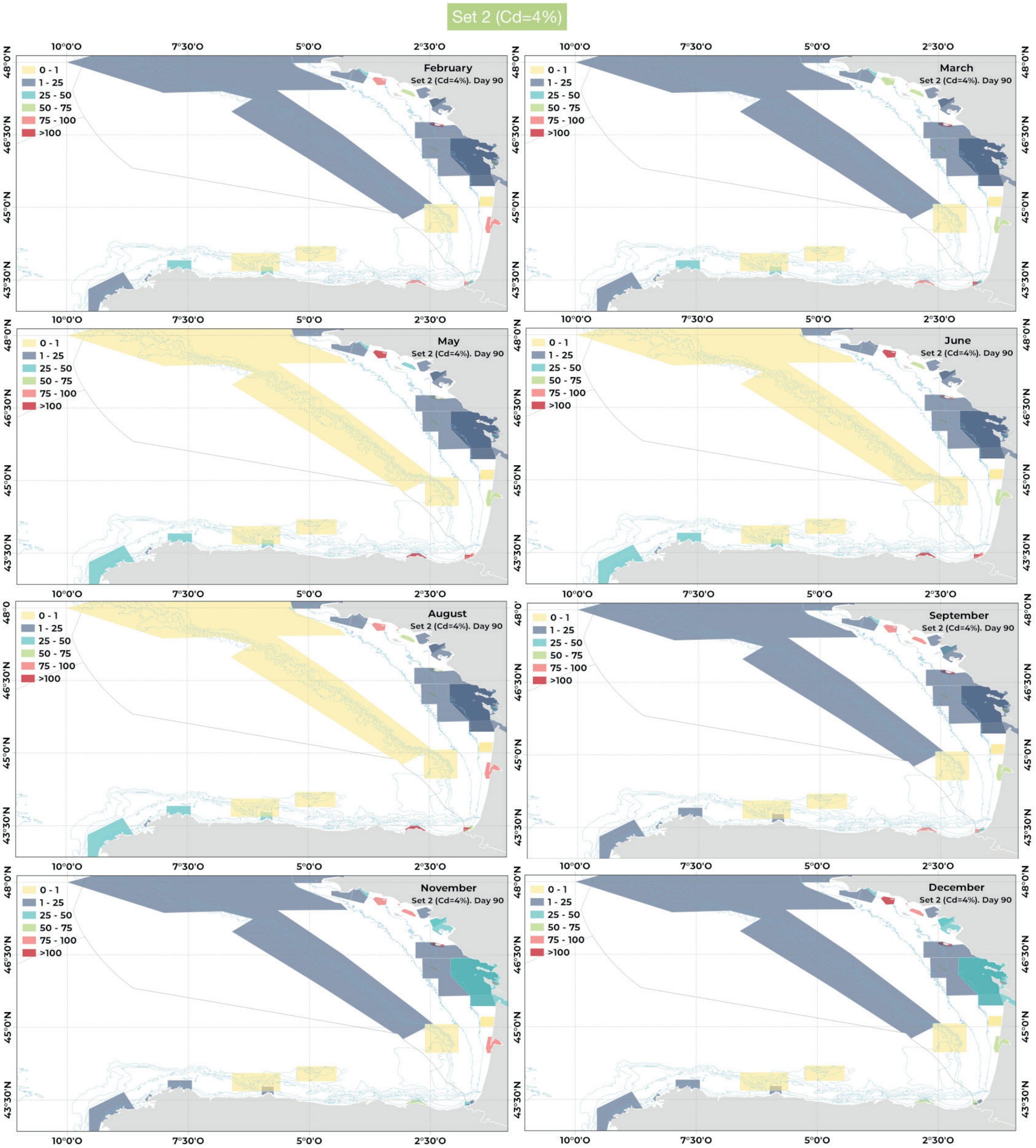
Supplementary Fig 5.14. Spatial particle accumulation for Set 2 after 90 days of simulation. The figures show the particle accumulation for the releasing initialized in February, March, May, June, August, September, November and December.

Supplementary Figure 5.15



Supplementary Fig 5.15. Concentration within the MPAs for Set 1 after 90 days of simulation. Concentrations in the MPAs (n/km2) were quantified as the ratio between particle accumulation by the end of the simulation and the MPA surface area. The figures show the particle concentrations for the releasing initialized in February, March, May, June, August, September, November and December

Supplementary Figure 5.16



Supplementary Fig 5.16. Concentration within the MPAs for Set 2 after 90 days of simulation. Concentrations in the MPAs (n/km2) were quantified as the ratio between particle accumulation by the end of the simulation and the MPA surface area. The figures show the particle concentrations for the releasing initialized in February, March, May, June, August, September, November and December

CHAPTER 5

Publication data

Type	Research article
Title	Modelling floating riverine litter in the south-eastern Bay of Biscay: a regional distribution from a seasonal perspective
Authors	Irene Ruiz1*, Anna Rubio1, Ana J. Abascal2 and Oihane C. Basurko1
Affiliation	1AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Pasaia, Spain 2 IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain
Journal	Ocean Science
Year	2022
Volume	-
Stage of publication	In review

ABSTRACT

Although rivers contribute to the flux of litter to the coastal and marine environment, estimates of riverine litter amounts are scarce and the behaviour of riverine litter at river mouths and coastal waters is highly uncertain. This paper provides a comprehensive overview of the seasonal trends of floating riverine litter transport and fate in the south-eastern Bay of Biscay based on riverine litter characterization, drifters and high-frequency radars observations and Lagrangian simulations. Virtual particles were released close to the river mouths as a proxy of litter entering the ocean from rivers and were parameterized with a wind drag coefficient (Cd) to represent their trajectories and fate according to the buoyancy of the litter items. They were forced with numerical winds and measured currents provided by high-frequency radars covering selected seasonal week-long periods between 2009 and 2021. To gain a better insight on the type and buoyancy of the items, samples collected from a barrier placed at Deba river (Spain) were characterized at laboratory. Items were grouped into two categories: low buoyant items (objects not exposed to wind forcing e.g., plastic bags) and highly buoyant items (objects highly exposed to wind forcing, e.g., bottles). Overall, low buoyant items encompassed almost 90% by number and 68% by weight. Low buoyant items were parametrized with Cd=0%, and highly buoyant items with Cd=4%, this later one as a result of the joint analysis of modelled and observed trajectories of four satellite drifting buoys released at Adour (France), Deba (Spain) and Oria (Spain) river mouths. Results show that all regions in the study area are highly affected by rivers within or nearby the region itself. Simulations of riverine litter parametrized with Cd=4% showed that particles drifted faster towards the coast by the wind, notably during the first 24 hours. In summer, over the 97% of particles beached after one week of simulation. In autumn this value fell to 54%. In contrast, the low buoyant litter items take longer to arrive to the coastline, particularly during Spring with fewer than 25% of particles beached by the end of the simulations. When comparing coastline concentrations, the highest concentrations of particles (>200 particles/km) were recorded during summer in the French region of Pyrénées-Atlantiques for Cd=4%. These results coupled observations and a river-by-river modelling approach and can assist policy and decision makers on setting emergency responses to high fluxes of riverine litter arrivals and on defining future monitoring strategies for heavy polluted regions within the study area.

INTRODUCTION

Rivers act as key vectors bringing improperly disposed and mismanaged litter from land into coastal and marine environments, especially in densely populated or highly industrialized river basins. Riverine litter poses a large threat not only to coastal and marine environments but also to freshwater systems by degrading aquatic life, impacting freshwater quality and increasing economic losses associated with human activities (van Emmerik and Schwarz, 2020; Al-Zawaidah et al., 2021). Recent findings derived from extensive modelling efforts suggest that about 1,600 rivers worldwide account for 80% of plastic inputs to the ocean with small urban rivers among the most polluting (Meijer et al., 2021). However, most of the litter research conducted to date has focused on marine environments (87%) when compared to freshwaters systems (13%), and only 7% of all scientific publications can be attributed to macroplastics (size > 2.5 cm) (Blettler et al., 2018). Riverine litter contributions to oceans are still uncertain, and results vary depending on the approach applied such as the dataset or the model used. Global estimates based on modelled amounts of mismanaged plastic waste (MPW) range between 0.5 to 2.7 million metric tonnes per year (Lebreton et al., 2017; Schmidt et al., 2017; Meijer et al., 2021); however, they can represent less than a tenth when methodology followed differ from MPW-based models (Mai et al., 2020). Models require comprehensive field data and consistent and harmonized protocols to validate the amounts, type and size of riverine inputs, information that can then be used to implement tailor-made and effective measures at regional and local scale (González-Fernández and Hanke, 2017; Wendt-Potthoff et al., 2020; Margenat et al., 2021). Such comprehensive data was obtained in Europe thanks to the RIMMEL project (González-Fernández and Hanke, 2017) and a network of visual observers of riverine macrolitter, which research concluded that between 307 and 925 million litter items are annually transferred into the ocean, mainly through small rivers, streams and coastal run-off (González-Fernández et al., 2021).

Once at the river mouth, riverine litter can accumulate nearby or it can move long distances, reaching remote areas from river waters. Indeed, the distribution and fate of riverine litter in the coastal and marine environment is conditioned by the metocean conditions (currents, turbulence, wind) but also by the buoyancy of the objects, defined by their composition, size and shape (Ryan, 2015; Lebreton et al., 2019; Maclean et al., 2021). Objects with low buoyancy are mainly driven by currents contrary to high buoyant items which are pushed along the water surface partially by winds. The wind effect (“windage”) is an important factor for pushing litter to shore and induce beaching, mainly for offshore-source litter, which is highly affected by winds, compared to coastal-source macrolitter (Ko et al., 2020). Riverine litter trapped in near-shore areas is susceptible to beaching, settling and resurfacing episodes and reach open ocean mostly as small fragments (Morales-Caselles et al., 2021), hampering cleanup efforts and contributing to the prevalence of litter in the marine environment. Adjustment for windage has been consequently investigated in Lagrangian modelling studies in open ocean (Allshouse et al., 2017; Maximenko et al., 2018; Lebreton et al., 2019; Abascal et al., 2009) but also, although less mature, in coastal areas (Critchell and Lambrechts, 2016; Utenhove, 2019; Tong et al., 2021). The lack of field data to accurately parametrize the effect of wind and validate simulation results is one of the key limitations both in riverine and marine transport modelling. From decades, researchers have used real observations derived from drifting buoys, such as in the Global Drifter program, which observations contribute to fill this gap.

Buoy data are used to fine-tuning prediction models and provide a better description of the near-surface circulation and its Lagrangian behaviour (Charria et al., 2013; Dagestad and Röhrs, 2019). They have also allowed simulating more realistic litter pathways from origin to fate by integrating experimental windage parametrizations and the corresponding comparison between observed and modeled trajectories (Duhec et al., 2015; Pereiro et al., 2018; Rizal et al., 2021). Satellite-tracked drifting buoys and communication systems are costly, despite more economical and environmentally friendly solutions are gaining force among researchers. Examples include drifters built using biopolymers (Novelli et al., 2017; D’Asaro et al., 2020) and compact and lightweight designs with a GPS-tracking component for an easy deployment (Meyerjürgens et al., 2019b; van Sebille et al., 2021). Others have evolved to develop drifters shaped as real litter items (e.g., plastic bottles), which allow a more accurate tracking position of standard objects, accounting for wind effect at sea and on inland waterways (Duncan et al., 2020).

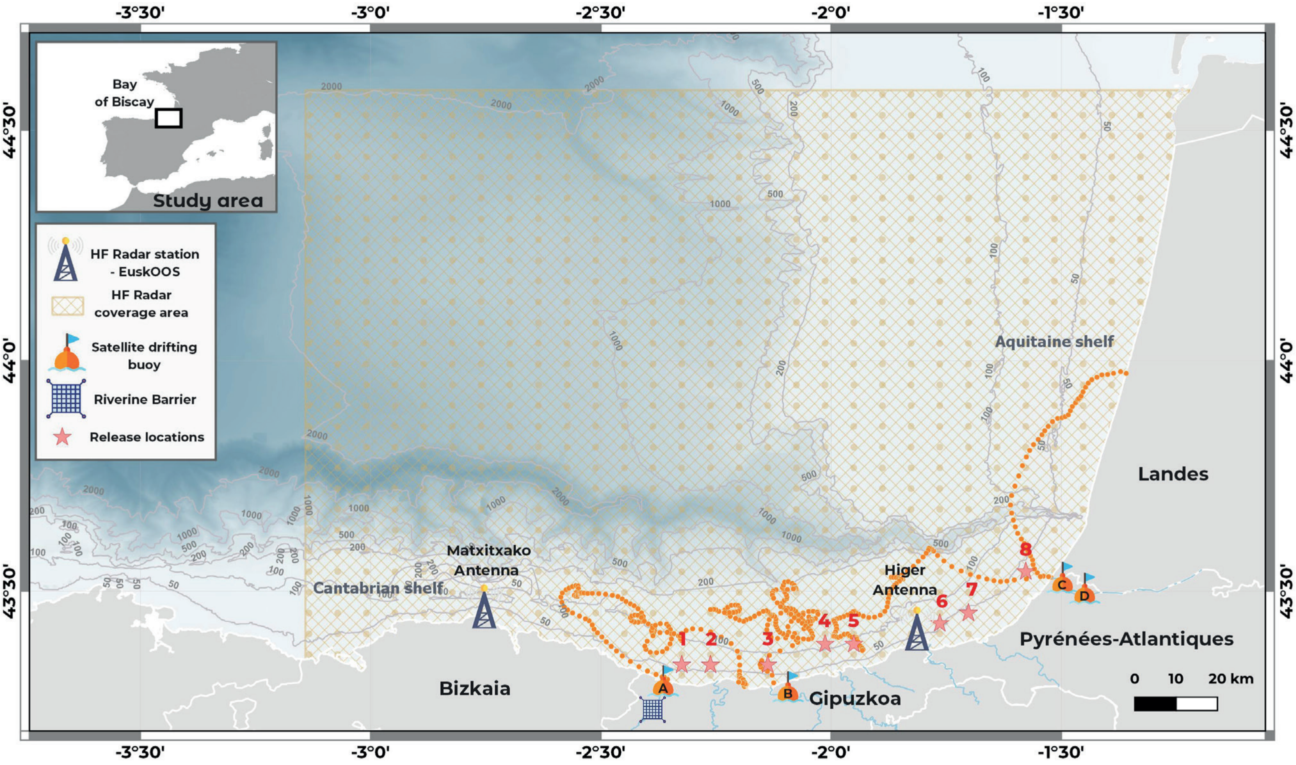


Fig 5.24. Study area with the release locations of the Satellite drifting buoys and the riverine barrier. Dots in orange represent the trajectories of the buoys. Numbers correspond to the particle releasing location for riverine litter simulations: (1) Deba; (2) Urola; (3) Oria; (4) Urumea; (5) Oiartzun; (6) Bidasoa; (7) Nivelle; and (8) Adour River. Dots in light yellow represent the nodes of the HF Radar grid.

Nowadays, coastal transport can be also characterized at high temporal and spatial resolution thanks to the use of land-based high frequency radar systems for the remote measurement of surface currents (hereafter HF radars (Rubio et al., 2017)). HF radars offer the opportunity to monitor surface currents in coastal areas, where the transport processes are significantly more complex than open ocean waters due to the effect of coasts, bathymetry and other local forcings, like river discharges or coastal upwellings. Given the highly dynamic and complexity nature of coastal waters, this realistic and useful knowledge on coastal circulation combined with the parametrization of key physical processes affecting litter transport (e.g., windage) become crucial to reduce the uncertainties of modelled trajectories of riverine and marine litter (Van Sebille et al., 2020).

In the the south-eastern Bay of Biscay (hereafter SE Bay of Biscay), a HF radar provides, as part of the operational oceanography system EuskOOS (https://www.euskoos.eus/), near-real-time surface current fields at 5 km spatial and 1-hour temporal resolution, covering since 2009 a range up to 150 km from the coast. This system has already been used in previously to study surface coastal transport processes in combination with multisource data (Manso-Narvarte et al., 2018, 2021; Rubio et al., 2011, 2013, 2018, 2020; Solabarrieta et al., 2014, 2015, 2016). The HF radar is also a good example of effective monitoring of surface currents with strong potential for floating marine litter management. The EuskOOS HF radar is part of JERICO-RI (https://www.jerico-ri.eu/) and it is operated following JERICO-S3 project best practices, standards, and recommendations. Research conducted by Declerck et al., (2019) in the SE Bay of Biscay provided the first assessment of floating litter transport and distribution in the region, coupling surface currents observations from EuskOOS system, Lagrangian modelling and riverine inputs. Nowadays, these observations are used by local authorities both in real time and in hindcast in the framework of the operational service FML-TRACK (https://fmltrack.rivagesprotech.fr/) to collect floating marine litter in the area. However, the accurate modelling of transport and fate of both floating marine and riverine litter need to consider the variety of floating objects and sources and additional physical processes as windage. This paper aims at estimating the seasonal trends on floating riverine litter transport and fate in the SE Bay of Biscay by modelling the Lagrangian behaviour of numerical particles released in the main rivers within the area. To do so, a Lagrangian model was forced by real observations from the EuskOOS HF radar and particles were parameterized to represent riverine litter trajectories according to their observed buoyancy. Riverine litter collected from a local barrier was characterized at laboratory to explore the fraction of highly and low buoyant items. Since most of the items were low buoyant, simulations of particles considering only surface currents were performed as the reference. Complementary Lagrangian simulations for highly buoyant items (and less abundant in the area) were also performed. In this case, 4 low-cost buoys with similar buoyancy of certain highly buoyant objects were built and released at 3 different rivers. Drifter data were used to parameterize the wind effect on this type of items and consequently achieve more accurate results.

METHODS AND DATA

Riverine Litter Sampling

In Spring 2018, a riverine barrier was placed in Deba river (Gipuzkoa) to retain and collect floating macro riverine litter during low to moderate flows. The barrier, which consisted of a nylon artisanal net supported by hard floats (buoys) was 40 m long and 0.6 m high with a 60 mm mesh size (Supplementary Fig 5.17). A sampling was conducted weekly from April 2018 to June 2018; in total eight riverine litter samples were collected.

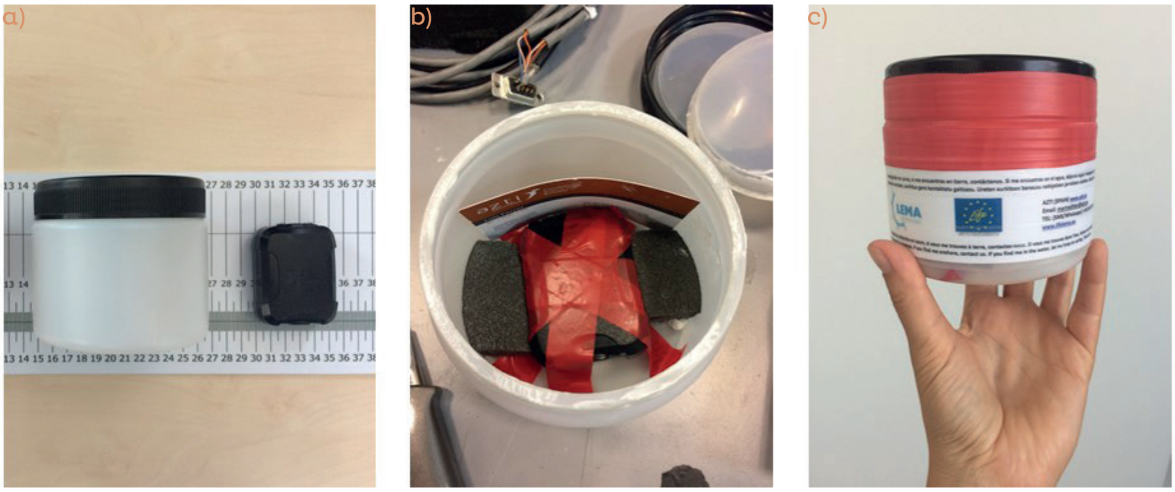


Fig 5.25. Main components of the "Low-cost buoy". The structure: (a) HDPE container and SPOT Trace device powered by 4 AAA cells. Assembly process: (b) final appearance once the buoy is sealed. The buoy is labelled with contact information both within and outside; (c) the SPOT Trace was fixed at the base of the container with adhesive tape to avoid twists and turns of the buoy.

Table 5.10. Locations, periods, and distances covered by the drifting buoys

Buoy ID	River	Initial date	Final date	Distance covered (km)
A	Deba	16-Sept-2018 8:00	4-Oct-018 7:00	116.1
B	Oria	12- Apr-2018 16:00	18-Apr-2018 12:00	118.72
C	Adour	29-Jul-2018 20:00	2-Aug-2018 20:00	71.21
D	Adour	28-Nov-2018 9:00	30-Nov-2018 11:00	64.41

Litter items were quantified, weighted, and categorized at lab according to the Master list included in the "Guidance on Monitoring of Marine Litter in European Seas" (Galgani et al., 2013) Items were grouped into 7 types of material (artificial polymer materials, rubber, cloth/textile, processed/worked wood, paper/cardboard, metal, and glass/ceramics) and further classified into 44 categories (see the classification in Supplementary Table 5.9). Riverine litter items were also categorized into two groups (low and highly buoyant items) considering their exposure to wind based on (Ruiz et al., 2022).

Drifters Observations

Four satellite drifting buoys (herein after 'low-cost buoys') were built by the authors and deployed one-by-one in the river mouths of Oria (1 buoy), Deba (1 buoy), and Adour (2 buoys) between April 2018 and November 2018 (Fig 5.24, Table 5.10). The 'low-cost buoys' provided positioning every 5 minutes using satellite technology. 'Low-cost buoys' were 9 cm in height, 9.5 cm in float diameter and weighed approximately 200 g (Fig 5.25). A GPS (SPOT Trace device) was placed in the bottom of a high-density polyethylene HDPE plastic container sealed to guarantee water tightness. Almost 2/3 of the buoy floated above the water surface thus preventing any satellite signal losses. Transmission periods relied upon battery lifetime and buoys landing.

HF radar Current Observations and wind data

Surface velocity current fields were obtained from the EuskOOS HF radar station composed by two antennas located at Matxitxako and Higer Capes and covering the SE Bay of Biscay (see (Solabarrieta et al., 2016; Rubio et al., 2018) for details). Data consist of hourly current fields with a 5 km spatial resolution obtained from using the gap-filling OMA methodology (Kaplan and Lekien, 2007; Solabarrieta et al., 2021). Data used for the Lagrangian simulations were extracted considering the outputs from the standard QC (quality control) procedures for real-time HF radar data (Rubio et al., 2021). Once extracted, data were visually inspected to ensure a complete radial coverage (i.e., ensuring optimal OMA reconstructed fields) and build data subsets for the Lagrangian simulations avoiding periods with temporal gaps of more than a few hours (Supplementary Table 5.10, Supplementary Fig 5.18).

Hourly ERA5-U10-wind fields were obtained from the atmospheric reanalysis computed using the IFS model of the European Center for Medium-Range Weather Forecast (ECMWF) (see (C3S, 2019) for details). ERA5 atmospheric database covers the Earth on a 30 km horizontal grid using 137 vertical levels from the surface up to a height of 80 km and provides estimates of a large number of atmospheric, land and oceanic climate variables on a 0.3° × 0.3° grid, currently from 1979 to within 3 months of real time. Both HF radar current observations and wind data cover the drifter's emission periods and the selected week-long periods between 2009 and 2021 for riverine litter simulations.

Particle Transport Model

The transport module of the TESEO particle-tracking model (Abascal et al., 2007, 2017a, b; Chiri et al., 2020) was applied to simulate the transport and fate of riverine litter items from selected rivers once they arrive to the coastal area. Simulations were forced by HF radar surface current velocity and wind data. The transport module was also used to accurately estimate the windage coefficient by calibrating the model according to the 'low-cost buoys' trajectories. TESEO has been calibrated and validated by comparing virtual particle trajectories to observed surface drifter trajectories at regional and local scale (Abascal et al., 2009, 2017a, b; Chiri et al., 2019). Although the TESEO is a 3D numerical model conceived to simulate the transport and degradation of hydrocarbons, it has also been successfully applied to other applications such as the study of transport and accumulation of marine litter in estuaries (Mazarrasa et al., 2019; Núñez et al., 2019) and in open waters (Ruiz et al., 2022).

Wind drag estimation

Two simulation strategies were combined for (1) estimating the wind drag coefficient and (2) study the seasonal behaviour of riverine litter items in the area (section 3.5.2) The wind drag coefficient (Cd) was determined by comparing the observed trajectories provided by the 'low-cost buoys' and the modelled trajectories performed with TESEO. The test was done through different parametrizations of the wind drag coefficient ranging from 0% to 7% (Table 5.11). This range was chosen based on previously floating marine litter studies coupling Lagrangian modelling and observations from satellite drifting buoys (Carson et al., 2013; Stanev et al., 2019; Van Der Mheen et al., 2019). The coefficient providing the lowest error was considered the best coefficient to simulate highly buoyant litter. Due to the grid limitations of the surface currents and wind data in the coastal area, the comparison was not initialised at the launching position of the 'low-cost buoys' (river mouths) but instead it was initialised at the closest grid element that contained valid currents and wind data (Table 5.10). Observed positions were interpolated onto a uniform one-hour time, fitting the met-ocean temporal resolution. A release of 1,000 virtual particles was performed every 4 hours at the corresponding observed position (Table 5.11). Particles were tracked over a 24-hour period and the trajectory of the center of mass of all the particles was computed particles was computed at every time step to represent the track of the particle cloud. Observations were compared to modeled trajectories using the simple separation distance, which is the difference between the observed and the computed position of the center of mass at a time step t. Mean separation distance $\overline{D(t^{mod})}$ was calculated for every modelled position based on the simple separation distance following Eq. (1):

$$\overline{D(t^{mod})} = \frac{1}{N}\sum_{i=1}^{N} \left|\vec{X}^{mod}(t^{mod}) - \vec{X}^{obs}(t^{obs})\right| \quad (1)$$

where $\vec{X}^{mod}(t^{mod})$ and $\vec{X}^{obs}(t^{obs})$ are the modeled and observed trajectories for the simulation period i of a total of N periods. A mean separation distance curve was computed for every wind drag coefficient derived from the mean separation distance curves of the four buoys. The area beneath the mean separation distance curve was calculated to select the more suitable wind drag coefficient. The area $\widetilde{D}$ was calculated as a numerical integration over the forecast period via the trapezoidal method following Eq. (2):

$$\widetilde{D} \approx \int_{t^{mod}=1}^{t^{mod=24}} \overline{D(t^{mod})}\,dt \quad (2)$$

Lagrangian seasonal simulation of riverine litter items

Seasonal simulations were run for low and highly buoyant items to assess the seasonal differences on riverine litter transport and fate. As parametrizations concerning wind effect linked to the object characteristics are scarce, the optimal wind drag coefficient estimated for the buoys was accounted for simulated the behaviour of the objects highly exposed to wind. No wind drag parametrization (Cd=0%) was applied for low buoyant objects not subjected to wind effect. A total of ten periods per season uniformly distributed within the study period (2009-2021) were considered for the simulations based on the availability of HF radar surface current datasets. In total, 4,000 particles were released in 8 rivers for each selected period (500 per river) (Table 5.11). Simulations were run for 7 days. The total number of particles modeled for Cd=0% was the same as Cd=4%. Particles were released around 2.5 nautical miles off the coastline due to the complexity in resolving small-scale processes in and near the river mouths. A post-processing was carried out to compute by river: (1) the particles evolution over the time from their

Table 5.11. Simulation, release, and physical parameter values for wind drag estimation and floating riverine litter simulations.

	Simulation parameters			**Release parameters**		**Physical parameters**	
	Number of particles	**Integration time**	**Time step**	**Release locations**	**Release time**	**Turbulent diffusion coefficient**	**Wind drag coefficient (Cd)**
Simulations for wind drag estimation	1,000 per location	24 h	60 s	At the observed locations of the buoy	Over the emitting period of the buoy at spaced inter-vals of 4 hours	1 m2/s	0 %, 2%, 3%, 4%, 5%, 6% , 7%
Seasonal riverine litter simulations	500 per river	1 week	60 s	At a distance of 2.5 nautical miles from the river mouth	At the be-gin-ning of the selected time period (10 periods per season)	1 m2/s	0 %, 4%

release until their arrival to the coastline; and (2) the particles distribution on the coastline, counting the number of beached particles per km of coastline and indicating the spatial concentration per region.

RESULTS

Riverine litter characterization

In total 1,576 items and 11.597 kg of riverine litter were sampled and characterised (Fig 5.26). Plastic was the most common type of riverine litter in terms of number of items (95.1%) and in weight (67.9%); they were also frequent Glass/ceramics (16.1%) and Cloth/textile items (6.9%) when counted by weight. The top ten litter items accounted for 93.3% by number and 72.6% by weight of the total riverine litter (Table 5.12). Plastic/polystyrene pieces between 2.5 cm and 50 cm and Other Plastic/polystyrene identifiable items (e.g., food labelling) were the most abundant in terms of number (71.2%) and weight (16.9%). Low buoyant items encompassed almost 91% by number and 68% by weight of litter items (Fig 5.27).

Wind drag coefficient for drifting buoys

Total distances covered by drifting buoys ranged from 62 km to 118 km (Table 5.10) and they all spread out over the rivers inside the HF radar coverage area, spanning approximately 44ºN and 2º 22'W. They provided position data over 385 h before beached on Landes and Gipuzkoa coastlines. When compared with numerical trajectories obtained using different Cd parameterizations, the mean separation distance $\overline{D(t^{mod})}$ increased nearly linearly with time for all the parametrizations, achieving a maximum separation of almost 14 km at 24 hours for Cd=0% (Fig 5.28). Overall, using no windage parametrization gave the largest $\widetilde{D}$. Simulations parametrized with Cd=4% gave the best results with an average ± standard deviation (SD) of 3.2 ± 1.25 km and a maximum value of 4.85 km at 24 h. When assessing the mean separation distance for all the modeled positions at every observed position of the buoys, the most common range separation distance for Cd=4% was 2- 4 km (Fig 5.29). Hence, a wind drag coefficient of 4% was applied in the remaining analysis to estimate riverine litter behaviour of highly buoyant items.

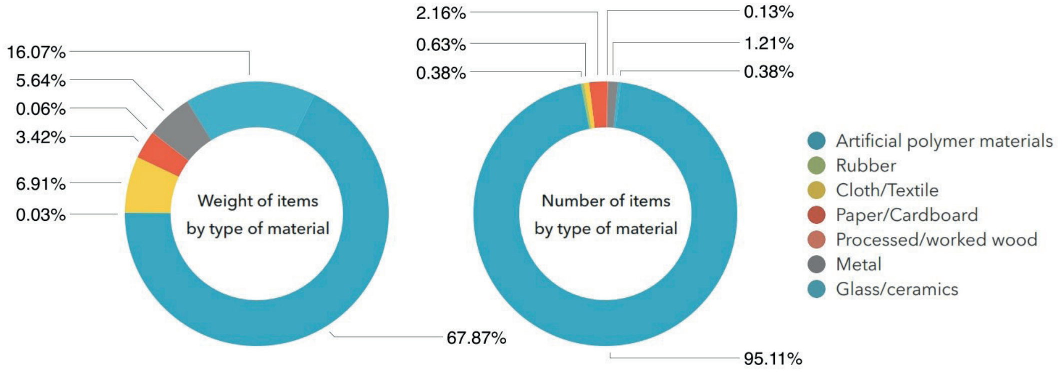


Fig 5.26. Composition by type of material based on the number and weight of riverine litter items collected in the riverine barrier located in Deba river (Gipuzkoa) between April and June 2018.

Table 5.12. Top ten (X) riverine litter items collected in the riverine barrier located in Deba river (Gipuzkoa) between April and June 2018. Items have been ranked by abundance (left) and weight (right) according to the MSFD Master List Categories of Beach Litter Item and classified based on their exposure to wind effect.

		Top X by number of items		
Ranking	TSG_ML General code	General name	Number of items (%)	Type of item
1	G76	Plastic/polystyrene pieces 2.5 cm >< 50 cm	71.19%	Low buoyant
2	G10	Food containers incl. Fast food containers	6.21%	Highly buoyant
3	G124	Other plastic/polystyrene items (identifiables)	3.68%	Low buoyant
4	G30	Crips packets/sweet wrappers	3.55%	Low buoyant
5	G20-G24	Plastic caps and lids/Plastic rings	2.41%	Low buoyant
6	G96	Sanitary towels/panty liners/ backing strips	2.22%	Low buoyant
7	G158	Other paper items	1.33%	Low buoyant
8	G5	What remains of rip-off plastic bags	1.33%	Low buoyant
9	G77	Plastic/polystyrene pieces >50 cm	0.82%	Low buoyant
10	G3	Shopping bags incl.pieces	0.51%	Low buoyant
		TOTAL	93.25%	

		Top X by weight of items		
Ranking	TSG_ML General code	General name	Weight (%)	Type of item
1	G124	Other plastic/polystyrene items (identifiables)	16.88%	Low buoyant
2	G200	Bottles incl. Pieces	15.80%	Highly buoyant
3	G76	Plastic/polystyrene pieces 2.5 cm >< 50 cm	9.48%	Low buoyant
4	G96	Sanitary towels/panty liners/backing strips	9.48%	Low buoyant
5	G10	Food containers incl. Fast food containers	6.04%	Highly buoyant
6	G135	Clothing (clothes, shoes)	4.16%	Low buoyant
7	G77	Plastic/polystyrene pieces > 50 cm	2.91%	Low buoyant
8	G145	Other textiles (incl.rags)	2.77%	Low buoyant
9	G175-G176	Cans (beverage/food)	2.60%	Highly buoyant
10	G3	Shopping bags incl.pieces	2.52%	Low buoyant
		TOTAL	72.64%	

FLOATING RIVERINE LITTER CLASSIFICATION BY WIND EXPOSURE

	Highly buoyant items	Low buoyant items
Number of items	1,436	140
Weight of items (kg)	7.880	3.717

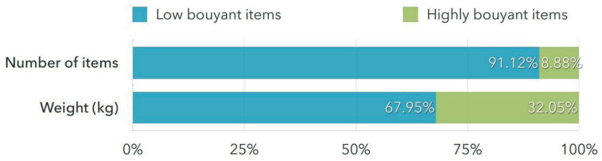


Fig 5.27. Riverine litter items classification based on the exposure to wind effect, from riverine litter items collected in the riverine barrier located in Deba river (Gipuzkoa) between April and June 2018.

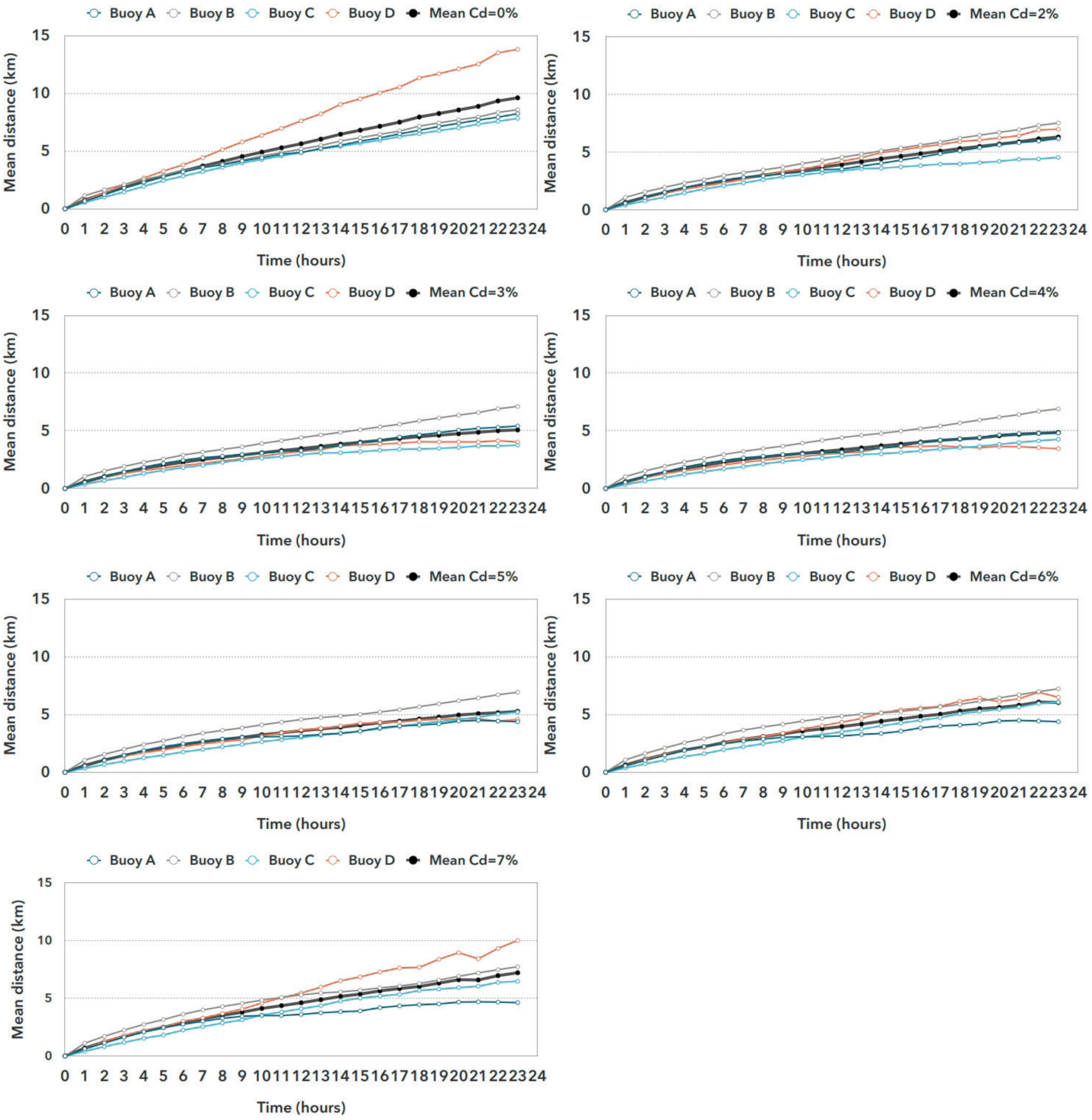


Figure 5.28 Mean separation distance between modelled and observed trajectories for each wind drag coefficient. The dark line is the mean curve employed for the trapezoidal integration.

Seasonal trends on floating riverine litter transport and fate

Particle concentrations in the coastline varied between 0 and 258.46 particles/km (Fig 5.30). Particles parametrized with Cd=4% drifted faster towards the coast by the wind, notably during the first 24 hours. The highest concentrations (>200 particles/km) were recorded during summer in Pyrénées-Atlantiques for Cd=4%, probably due to the seasonal retention patterns within the study area (Supplementary Fig 5.18). Although less intensely, Cd=4% also lead to a high particle concentration in Pyrénées-Atlantiques (106.86 particles/km) and Gipuzkoa (166.1 particles/km) during winter. Lowest concentrations (0-20 particles/km) were recorded for Cd=0% at all seasons during the first 24 hours and particularly during autumn. Overall, Bizkaia was the less affected by litter for both windage coefficients (<40 particles/km). When looking at the total amounts of beached particles per season, in summer over the 97% of particles parametrized with Cd=4% beached after one week of simulation (Fig 5.31). In autumn this value fell to 54%.

In contrast, particles parametrized with Cd=0% take longer to arrive to the coastline, particularly during Spring with fewer than 25% of particles beached by the end of the simulations. According to the temporal evolution of floating particles released per river, particles beached remarkably fast within the first 24-48 hours for Cd=4%, particularly those released during summer in French rivers. Similar behaviour pattern was observed within the same season between rivers, probably influenced by the vicinity of rivers and the spatiotemporal resolution of forcings (Fig 5.32). When looking the seasonal trends by river and region, beached particles were mainly found in Gipuzkoa for both Cd=4% and Cd=0% - 40.1% and 11.54% of the total particles released respectively -, particularly in winter after one-week of simulations. For Cd=0%, beaching from particles released in Bidasoa, Nivelle and Adour River was higher in summer (9.01% particles released during summer) though this trend was reversed in autumn, when particles released in Basque rivers resulted in higher beaching. Overall, all regions were highly affected by rivers within or nearby the region itself (Fig 5.33).

DISCUSSION

Riverine litter composition

In this study, an artisanal net placed at the mouth of Deba river provided a practical and tailored application for aggregating riverine in the study area during Spring 2018. Short and narrow rivers prevail in the SE Bay of Biscay particularly affected by a strong tidal regime, and very intense, stationary and persistent storms caused by a combination of a warm sea, an unstable surface atmosphere and cold air at higher altitudes (Ocio et al., 2015). First field studies aiming at reporting the abundance and composition of floating riverine litter in European rivers date back less than 10 years and they were performed mainly in larger and more abundant rivers than Deba river. Despite the morphology and hydrological differences between rivers, the distribution of items by type of material in Deba river showed a clear predominance of plastic as observed in Siene (Gasperi et al., 2014), Danube (Lechner et al., 2014) or Rhine River (van der Wal et al., 2015). Similarities were also found when comparing the Topte n list of riverine litter items to rivers located in the North-East Atlantic region. Plastic/polystyrene pieces between 2.5 cm and 50 cm top the list in terms of number of items, accounting for a greater proportion in Deba river (71.2%) than in North-East Atlantic rivers (54.53%)(Bruge et al., 2018; Gonzalez-Fernandez et al., 2018).

Riverine litter items trapped on vegetation or deposited on the riverbank can be degraded by weather conditions (rain, wind, etc.) favouring the fragmentation in plastic pieces before their arrival to the coastal and marine environment. Higher percentages of Plastic/polystyrene pieces between 2.5 cm and 50 cm observed in the study than those of the Black Sea (13.74%) or the Mediterranean Sea (25.01%) can be attributed to a higher and faster fragmentation of riverine items along Deba river and the North-East Atlantic basins. Results are also in line with the ranking list of the Top ten beach litter items across the North-East Atlantic region revealing that Single Use Plastics (i.e. food containers, bottles and other packaging) are among the most abundant riverine litter items together with plastic fragments (Addamo et al., 2017). These results differed from the analysis performed in sea small-scale convergence areas of floating marine litter ("litter windrows") on the coastal waters of the SE Bay of Biscay, where fishing-related items were the

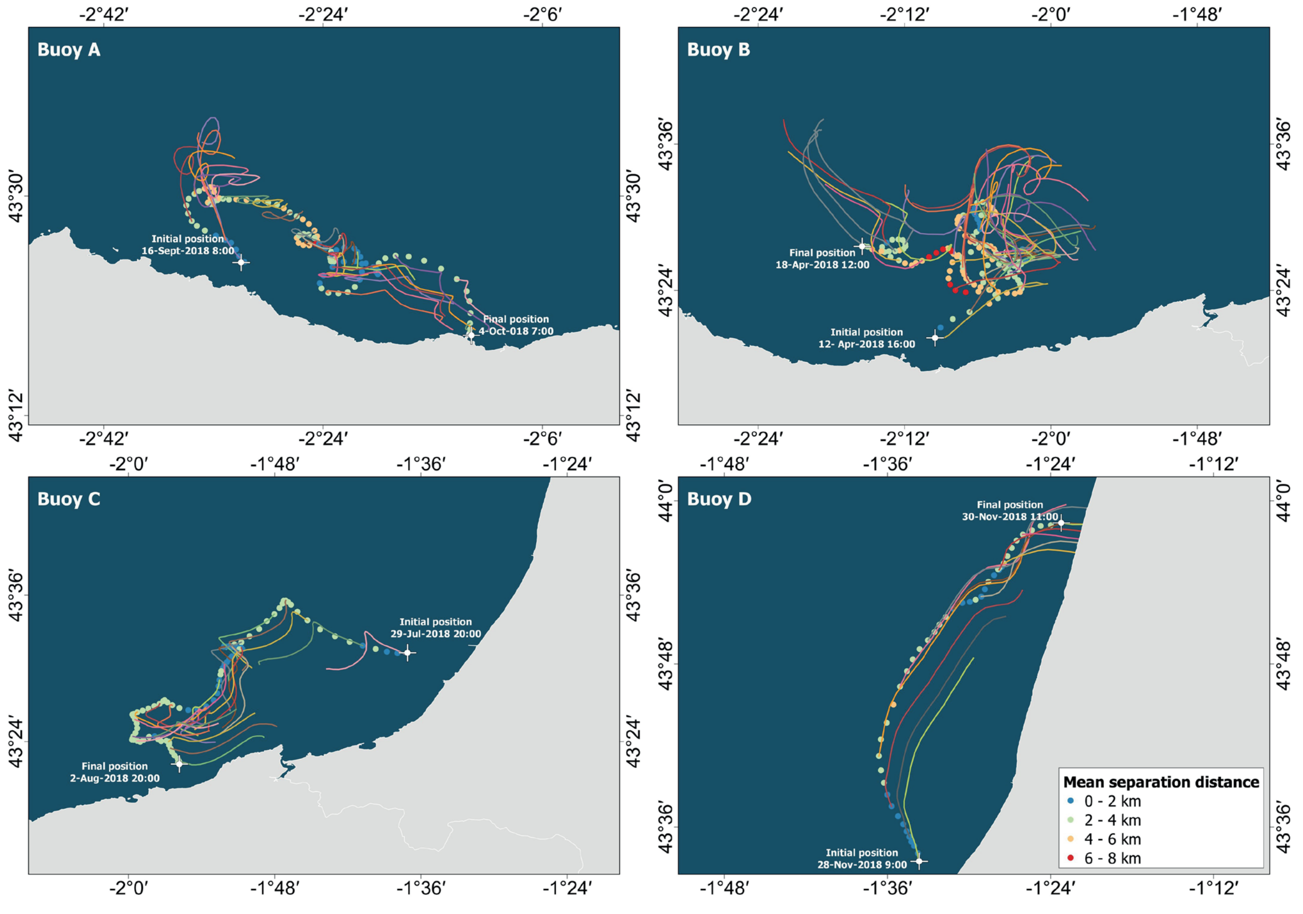


Figure 5.29. Spatial mean distance between modeled and observed trajectories of buoy A, B, C and D with a drag coefficient Cd=4%. Particle trajectories were simulated during 24 h, with a re-initialization period every 4 hours. The modeled trajectories are shown in solid lines. Circles represents at the observed position the mean separation distance for all the modeled position.

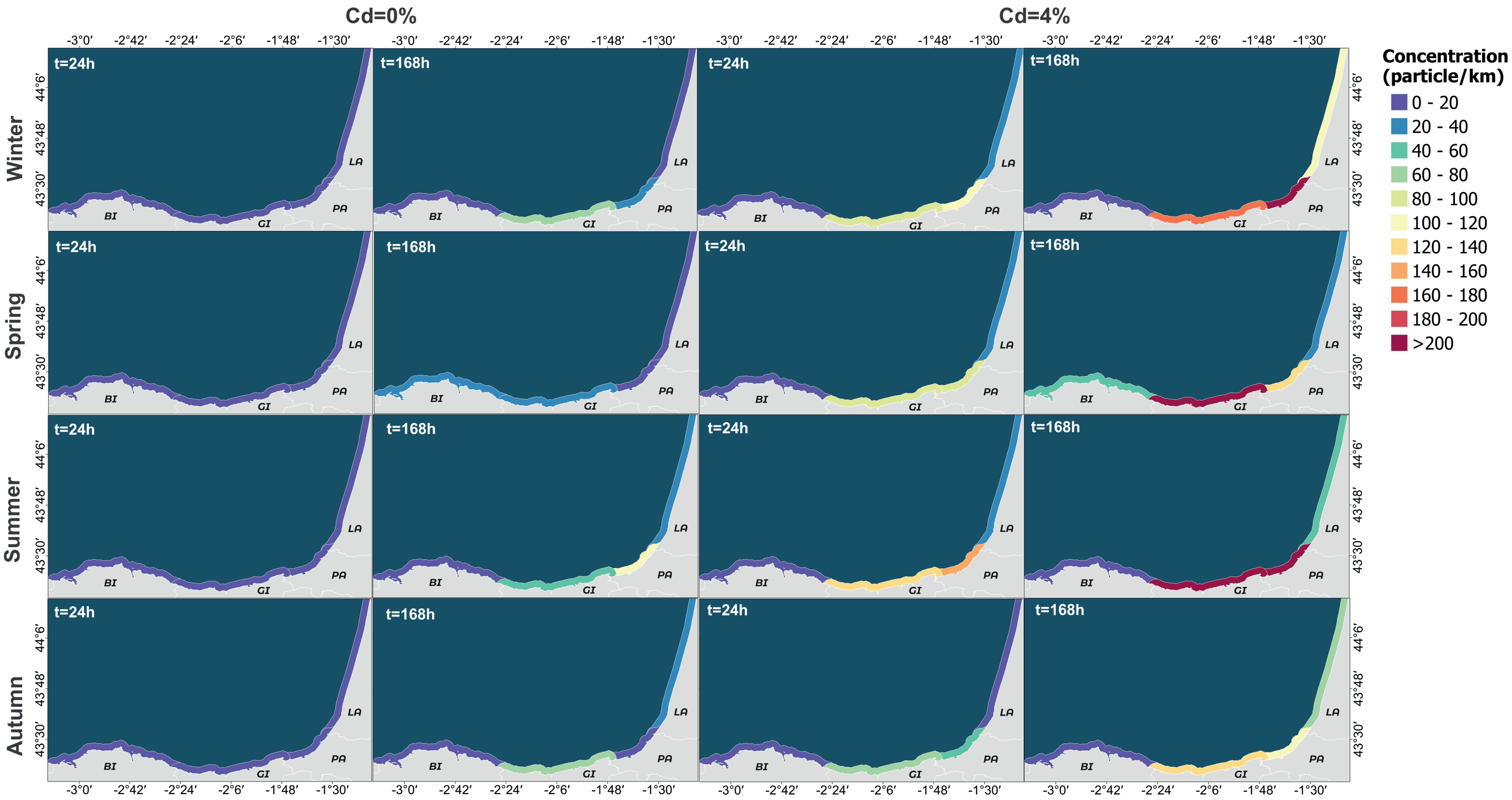


Figure 5.30. Particle concentration in Bizkaia, Gipuzkoa, Pyrénées-Atlantiques and Landes coastlines. The seasonal distribution is shown for wind drag coefficient Cd=0% and Cd=4% after 24 hours and 168 hours of simulation

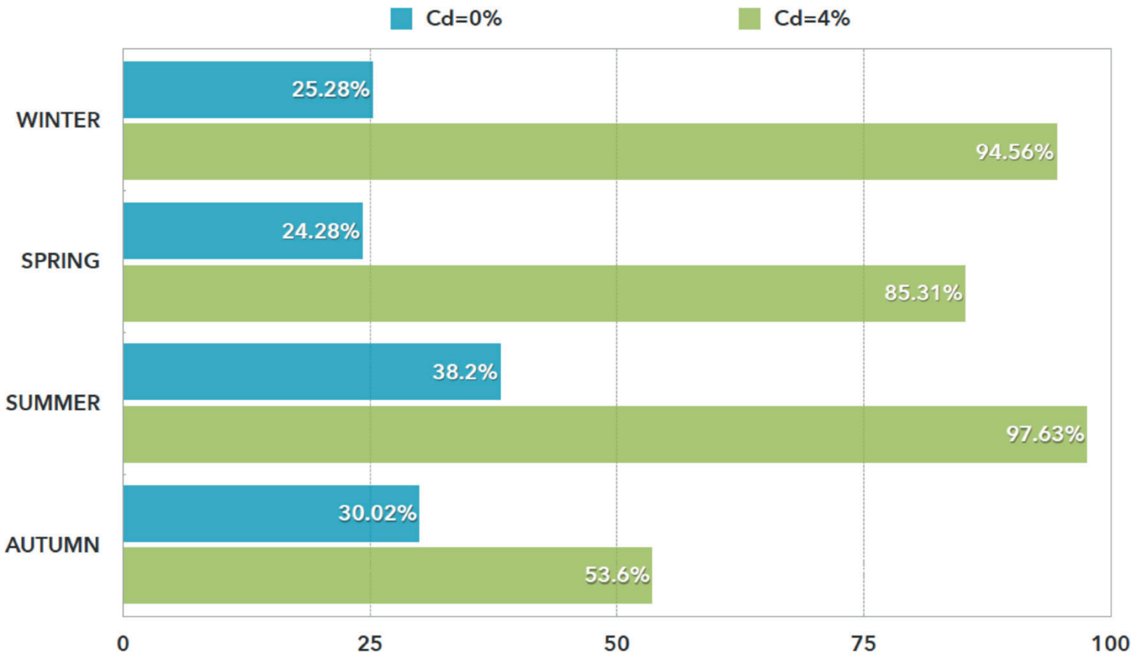


Figure 5.31. Total amounts of beached particles per season after 168 hours of simulation for wind drag coefficient Cd=0% and Cd=4%.

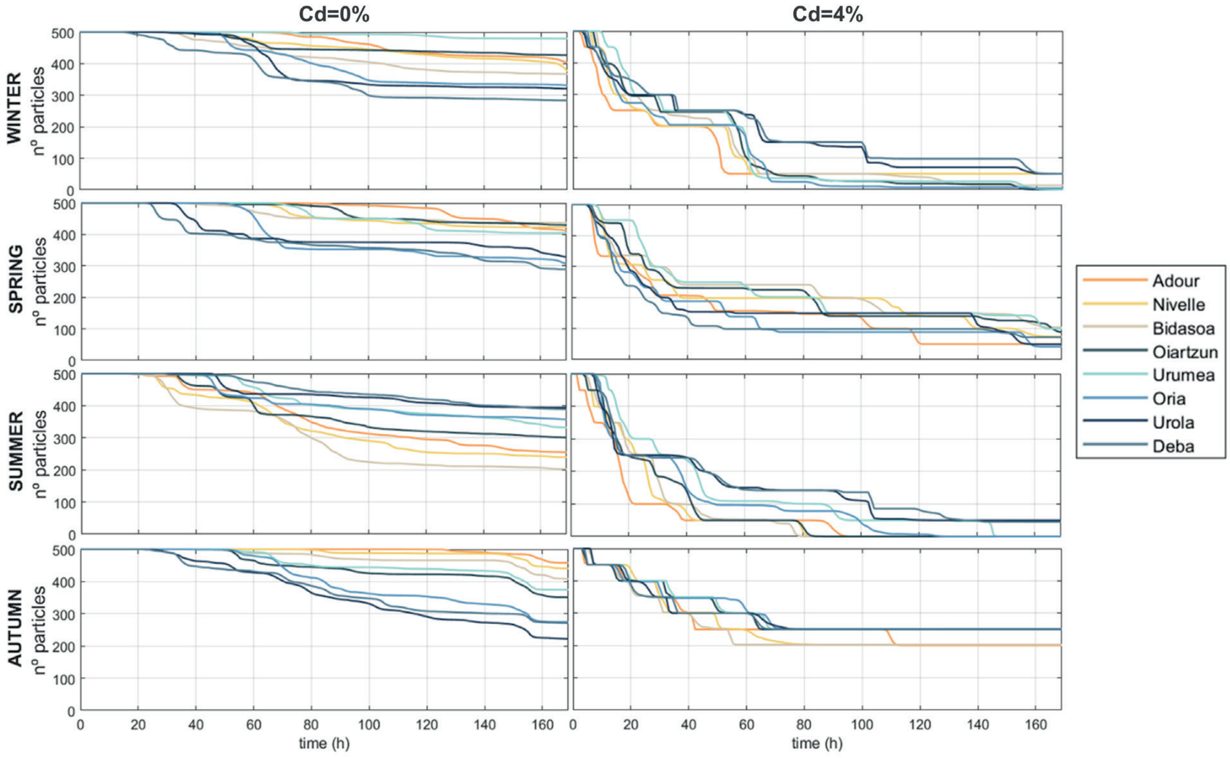


Figure 5.32. Temporal evolution of the particles released by river during the simulation period for a wind drag coefficient Cd=0% and Cd=4%. The curves represent the number of floating particles in the water surface for every time step.

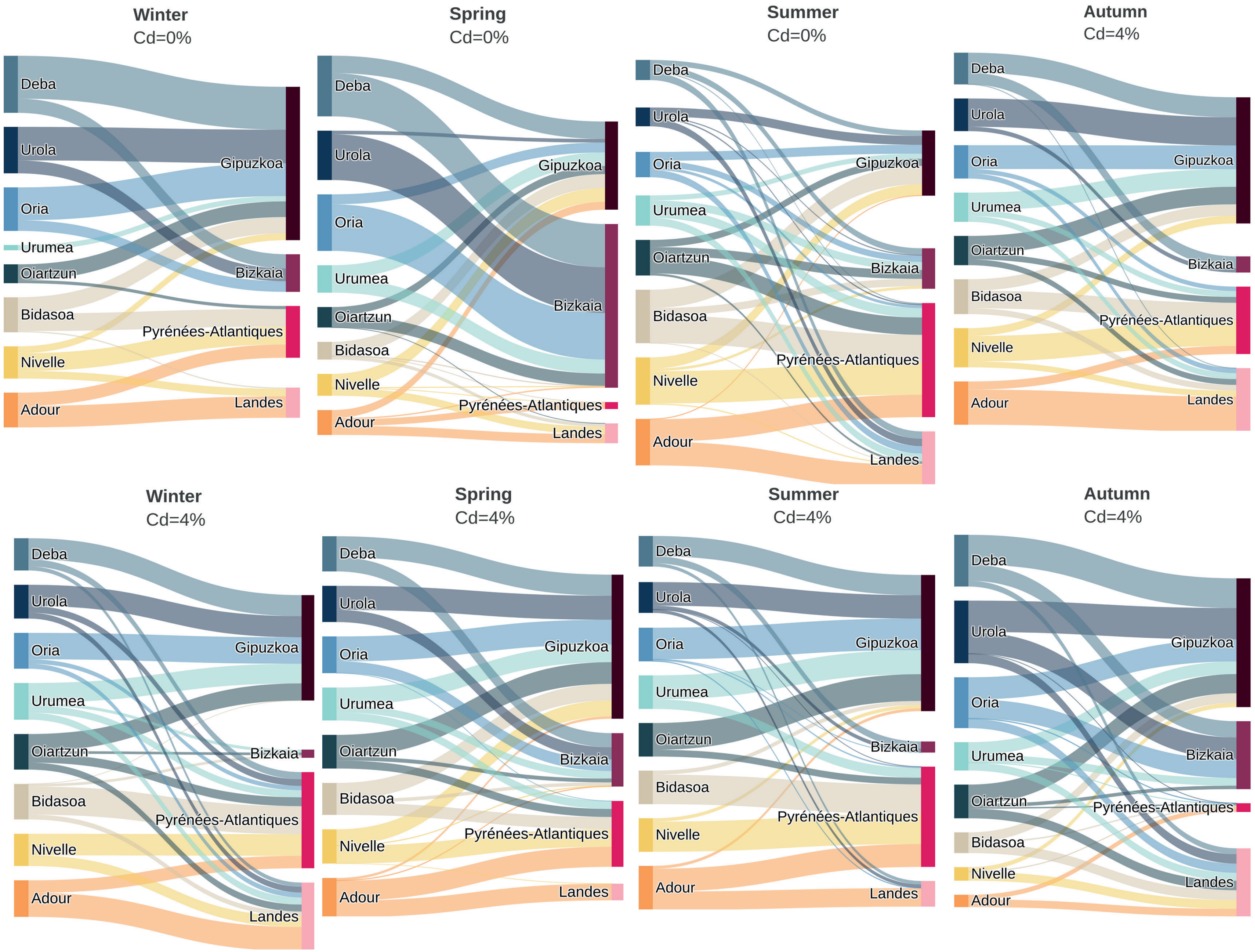


Figure 5.33. Seasonal analysis of beached particles per region and river for wind drag coefficient Cd=0% and Cd=4% by the end of the simulation period. The nodes of the region correspond to the number of beached particles. The width of the node depicts the sum of the beached particles, and the links represent the number of particles beached per river.

second most abundant sub-category in terms of number after Plastic/polystyrene pieces between 2.5 cm and 50 cm (Ruiz et al., 2020a). Substantial differences also exist between riverine litter sampled in Deba river and floating marine litter assessed by visual observation from research vessels in open waters of the Bay of Biscay (Ruiz et al., 2022). Differences might be related to the monitoring method and, also, to the size of the items, since small items, as plastic pieces, can be overlooked by the observer when visual counting method is applied, contrary to riverine litter samplings for later analysis at lab. Overall, riverine litter data acquisition is mainly focused on the floating fraction and the litter loads under the surface water are often ignore. Increasing the quantity of rivers sampled, the frequency and the riverine water compartments is necessary to establish the composition and trends of riverine litter in the SE Bay of Biscay.

Wind drag estimation

One of the largest uncertainties for simulating floating litter behaviour is the proper quantification of a wind drag coefficient. Empirical data provided by "Low-cost buoys" combined with surface current measurements by HF radar can be used as a proxy for predict the drift of floating litter objects with similar buoy characteristics (density, size and shape) in the study area. Commercial SPOT Trace devices have been used over the past few years in coastal and open ocean applications in a wide range of studies. Studies range from calibrating HF radars (Martínez Fernández et al., 2021), tracking drifting objects as icebergs (Carlson et al., 2020), pelagic Sargassum (Putman et al., 2020; van Sebille et al., 2021) or fishing vessels (Widyatmoko et al., 2021; Hoenner et al., 2022), to search and rescue training (Russell, 2017) and oil spill and litter monitoring (Novelli et al., 2018; Meyerjürgens et al., 2019a; Mínguez et al., 2012; Abascal et al., 2015). Nevertheless, object characteristics may change over the time due to the exposure to wind, waves, UV radiation, seawater and the attachment of organic material (Kooi et al., 2017; Min et al., 2020). Objects become breakable, and biofouling increases their density, overcoming the positive buoyancy and impacting on their trajectory. Investigations so far pinpointed longer time scales (weeks to months, and lager) than considered in this study (days) for a significant change on the behaviour of floating objects (Ryan, 2015; Fazey and Ryan, 2016). Consequently, physical variations on the buoy properties were not accounted for wind drag estimation. The separation distance between observed and modeled trajectories has been commonly used to evaluate the skill of particle-tracking models (Callies et al., 2017; Haza et al., 2019; Aksamit et al., 2020; Abascal et al., 2012). In this study, the purpose was no to evaluate the model accuracy but estimated the wind drag coefficient for the "Low-cost buoys". However, the novel approach proposed by (Révelard et al., 2021) may be of particular interest for future experiments oriented to assess the wind drag coefficient of highly buoyant items drifting during short time periods in the coastal area. The results obtained for Cd=4% can be consistent with wind drag estimations for the Bay of Biscay of the partially emerged Physalia physalis (Ferrer and Pastor, 2017) but greater than the Cd=3% observed for the Prestige oil spill accident (Abascal et al., 2009; Marta-Almeida et al., 2013). Indeed, oil spill studies refer to a range of wind drag coefficient between 2.5 to 4.4% of the wind speed, with a mean value of 3 - 3.5% (e.g., ASCE, 1996; Reed et al., 1994). In this study, a wind drag value of 4% can be expected due to the strong buoyancy of the "low-cost buoys" and can be applied for simulating the transport and fate of a specific group of litter items that share similar characteristics. However, due to the large heterogeneity of highly buoyant items, further experiments are needed to better parametrize the wind drag coefficient of different objects and consequently reduce the uncertainties on their behaviour.

Seasonal riverine litter distribution by region

It is broadly accepted that the SE Bay of Biscay is polluted with floating litter discarded or lost at the marine and coastal area but also with litter originated inland and transported via rivers and runoff. However, detailed studies on riverine litter contribution are still scarce and modelling efforts combining observations and physical parametrizations of riverine litter properties are non-existent. This study shows that the exposure to wind effect of riverine objects largely control their transport and coastal accumulation in the SE Bay of Biscay, with concentrations varying between regions and over the time. Concentrations in Pyrénées-Atlantiques and Gipuzkoa regions diverged widely from the other studied regions. Indeed, the highest concentrations occurred in both regions during summer for low buoyant (100-120 particle/km) and but also for highly buoyant items (>200 particles/km). Although larger amounts of particles beached in Gipuzkoa during summer, concentrations are lower than Pyrénées-Atlantiques since the coastline in the Basque region is longer. Low buoyant pathways and fate reflect the well-known surface water circulation patterns in the SE Bay of Biscay. Concentrations of floating riverine litter are therefore a direct consequence of the seasonal variability of floating drift and results are in line with findings provided by (Declerck et al., 2019) who pinpointed a higher coastal retention in the area during spring and summer. Low buoyant objects not subjected to windage effects remain floating at the coastal waters and highly buoyant objects tended to beach remarkably faster as reported in literature by (Rodríguez-Díaz et al., 2020). However, long-term data collected by in-situ observations of beached litter across the different regions are necessary to validate the large seasonal variations and to assess the reliability of concentration levels for addressing riverine litter issue in priority regions with heavily polluted coastlines.

Rivers as key vectors of riverine litter

The interpretation of the spatial and temporal riverine litter distribution by river can be challenging since riverine litter fluxes in the study area are highly uncertain. In the study area, two major assumptions were made regarding the river systems: (1) same river discharge for all rivers and (2) same river discharge for all seasons. This means that same amounts of riverine litter were allocated for every river regardless the differences on the width and depth and the seasonal flow variations. Since each river basin has its own particularities, future modelling approaches should be adapted to the the morphology and hydrological conditions of the catchment area. Other drivers as the land use or socio-economic factors such economic status or population density can be a determining factor on the amount of mismanaged litter that could contribute to riverine litter fluxes (Schmidt et al., 2017; Schuyler et al., 2021). It is also necessary to further investigate if higher river flows in the area are directly related to an increased discharge of riverine litter since analysis already performed in different river basins show contradicting relations between the occurrence of riverine litter and river fluxes (van Emmerik and Schwarz, 2020). Along with the complex nature of qualifying riverine litter fluxes, litter behaviour in the coastal area of the SE Bay of Biscay is still in its early stage, and much has yet to be revealed.

Particular attention should be paid to Pyrénées-Atlantiques and Gipuzkoa, as main impacted regions in the studied area. The dominant number of rivers in this region can favour accumulation trends regardless the season. Regional coordination should be reinforced due to the transboundary movement of riverine litter in the study area and reasonable efforts oriented to retain or remove riverine litter as clean-up measures in the riverbanks should be investigated to avoid litter being transported to the coastal and marine environment.

Model limitations

The coastline of the SE Bay of Biscay is mainly covered by sand and muddy-sand and characterized by the presence of moderate to high sea rocky cliffs, especially in the Basque region (ICES, 2019; Bilbao-Lasa et al., 2020). The geomorphology can affect the retention of litter washing ashore. Sandy beaches tend to be more efficient at trapping and thus accumulating litter than rocky areas which favor litter fragmentation (Robbe et al., 2021; Weideman et al., 2020). Waves and tides can also constrain coastal accumulation since they can resuspend litter and transport it back into the ocean (Brennan et al., 2018; Compa et al., 2022). Nevertheless, research on these processes is scarce and they cannot be resolved yet at a suitable resolution (Melvin et al., 2021). Consequently, in this study once particles beached, they were classified as it arrived to their final destination. It is, however, important to consider for future research in the study area the link between coastal accumulation, and the type of shoreline and resuspension, even though the model cannot yet simulate these processes. The release location strongly influences where litter accumulates on the coastline. Litter items can beach rapidly when release locations are located near the coastline (Critchell et al., 2015). However, there is a big gap between the spatial resolution of ocean circulation models (up to 10 km spatial resolution) and the complex coastal accumulation processes. In this study, the release locations were located distant for the sources to avoid uncertainties on model performance at smaller scales. However, a greater model resolution with a finer grid can reinforce simulation results (NOAA, 2016). Nested models, flowing from fine resolution near critical locations as the river mouths to open ocean resolution is a worthy issue for future consideration.

Riverine litter collection and monitoring by a floating barrier

Riverine litter quantities on a global scale urge countries to keep rivers pollution-free, intercepting riverine litter before it reaches the ocean and minimizing the impact of marine pollution from land-based sources. Research to date suggest that a significant reduction of marine litter in the ocean can be achieved with collection at rivers or with a combination of river barriers and clean up ocean devices (Hohn et al., 2020). Large scale and innovative removal initiatives (e.g., deployment of interceptors at river mouths) are currently supporting cleanup actions worldwide on an experimental basis (Lindquist, 2016; Zhongming et al., 2019). At a smaller scale, oil spill booms or barriers have also been adapted to aggregate riverine litter in European river basins heavily exposed to the impacts of intense human activity, facilitating the collection and the analysis of litter composition (Gasperi et al., 2014). However, the efficiency of this type of devices is still not properly understood and can be conditioned by the wind, hydrology and morphological conditions of rivers (van Emmerik and Schwarz, 2020; Andrés et al., 2021). Storms result in large flows of water and thus riverine litter fluxes to the coastal and marine environment. A well-adapted device to storm-specific events must be considered when deciding which tools implement for a cost-effective plastic intervention strategy in the area. Further monitoring efforts are also required to account for seasonal variability on abundance and riverine litter typology. Within the LIFE LEMA project, two videometry systems were installed at the Oria and Adour river mouths and a detection algorithm was developed to monitor litter inputs in near real time (Delpey et al., 2021; Ruiz et al., 2020b). Besides monitoring, information collected by the videometry systems can complement floating barriers collection and sampling and advise local authorities for a quick response on riverine litter contribution to coastal area during storm events. Monitoring tools based on visual observations as RIMMEL or CrowdWater apps (González-Fernández, 2017; van Emmerik, 2020) can be also particularly helpful to build a database of riverine litter input to the SE Bay of Biscay so far remained limited or even non-existent, following a harmonized approach. Both data provided by cameras and visual observations can be crucial to evaluate the efficiency of mitigation measures as the installation of floating barriers as well as prevention measures applied inland the river basins for a successful reduction of litter inputs into the SE Bay of Biscay.

CONCLUSIONS

The SE Bay of Biscay has been regarded as an accumulation zone for marine litter but further improve understanding of floating macrolitter behaviour originated inland is required. Research on floating marine litter and pathways at sea are increasing but the understanding of the fate of floating macrolitter originated inland and transported through river systems is scarce and needs to be further studied. Based on HF radar current observations and wind dataset for the period 2009-2021, this contribution tries to fill this gap by providing insights on how low and highly buoyant riverine litter released by several rivers of the SE Bay of Biscay may affect the nearby regions seasonally in terms of concentration and beaching. Analysis of riverine samples collected by a floating barrier placed in the study area showed that low buoyant objects were predominant as riverine litter although highly buoyant objects were also relevant in terms of weight. Simulations for assessing the seasonal trends of floating riverine litter transport and fate were performed with the Lagrangian model TESEO. To properly integrate the differences in litter buoyancy, simulations were parametrized with a wind drag coefficient for low and highly buoyant items. The wind drag for highly buoyant item was estimated by comparing the observed and the modelled positions of four drifters and turned out to be greater than the commonly assumed value for oil spill studies. The developed “Low-cost buoys” proved to be suitable to provide real time trajectories of highly buoyant objects exposed to wind but drifters with different characteristics should be used in future studies for accounting the windage effect on different type of items. The transport and fate of both highly and low buoyant items released by rivers was calculated by season. Highly buoyant items rapidly beached (in less than 48 hours), particularly in summer and winter; in contrast, despite the season over two thirds of low buoyant items remained floating after one week of being released. This highlights the discrepancy between behaviour for low and highly buoyant objects and the importance of parametrizing the windage effect in order to accurately predict riverine litter accumulation in the coastal area of the SE Bay of Biscay. Beached particles were mainly found in Gipuzkoa regardless the season and the wind drag coefficient. Overall, the less affected region was Bizkaia with the exception of Spring period for low buoyant items. Despite of the season, most of the riverine the riverine litter remained in the study area and rivers polluted the regions within the river basin or surrounding. Investigating what beaches are most likely to accumulate large quantities and the contribution per river can provide relevant input to response operations after storm events in the short to medium term and can also support the identification of priority rivers for monitoring program, assisting in the future for an adapted intervention of riverine pollution regionally.

AUTHOR STATEMENT

IR: Investigation, formal analysis, visualization and writing – original draft preparation. AJ: Conceptualization, methodology, software, writing – review & editing. OCB: Conceptualization, supervision, resources, review and editing. AR: Conceptualization, methodology, supervision, resources, review and editing. All authors contributed to refining the manuscript for submission. This paper is part of the PhD research of IR supervised by OCB and AR.

ACKNOWLEDGEMENTS

We are grateful to the Emergencies and Meteorology Directorate – Security department – Basque Government for public data provision from the Basque Operational Oceanography System EuskOOS. Authors also acknowledge support from the JERICO-S3 project, funded by the European Union’s Horizon 2020 Research and Innovation Program under grant agreement no. 871153. This study has been conducted using EU Copernicus Marine Service information. We thank Luis Ferrer for sharing his valuable knowledge on custom-built the drifters. We thank Cristina Barreau, Antoine Bruge, Igor Granado, Théo Destang, Alix McDaid and Jon Andonegi for their support with drifters’ releasing. We thank the citizens who collected and reported drifters’ arrival to Basque and French coasts. This is contribution number XXX of AZTI - Marine Research (BRTA).

References

Abascal, A., Castanedo, S., Gutierrez, A. D., Comerma, E., Medina, R., and Losada, I. J.: Teseo, an operational system for simulating oil spills trajectories and fate processes, Proc. Int. Offshore Polar Eng. Conf., 1751–1758, 2007.

Abascal, A. J., Castanedo, S., Mendez, F. J., Medina, R., and Losada, I. J.: Calibration of a Lagrangian Transport Model Using Drifting Buoys Deployed during the Prestige Oil Spill, J. Coast. Res., 2009, 11,80-90, 2009.

Abascal, A. J., Castanedo, S., Fernández, V., and Medina, R.: Backtracking drifting objects using surface currents from high-frequency (HF) radar technology, Ocean Dyn., 62, 1073–1089, https://doi.org/10.1007/s10236-012-0546-4, 2012.

Abascal, A. J., Castanedo, S., Minguez, R., Medina, R., Liu, Y., and Weisberg, R.: Stochastic Lagrangian Trajectory Modeling of Surface Drifters deployed during the Deepwater Horizon Oil Spill, in: Proceedings of the 38th AMOP Technical Seminar on Environmental Contamination and Response, 77–91, 2015.

Abascal, A. J., Castanedo, S., Núñez, P., Mellor, A., Clements, A., Pérez, B., Cárdenas, M., Chiri, H., and Medina, R.: A high-resolution operational forecast system for oil spill response in Belfast Lough, Mar. Pollut. Bull., 114, 302–314, https://doi.org/https://doi.org/10.1016/j.marpolbul.2016.09.042, 2017a.

Abascal, A. J., Sanchez, J., Chiri, H., Ferrer, M. I., Cárdenas, M., Gallego, A., Castanedo, S., Medina, R., Alonso-Martirena, A., Berx, B., Turrell, W. R., and Hughes, S. L.: Operational oil spill trajectory modelling using HF radar currents: A northwest European continental shelf case study, Mar. Pollut. Bull., 119, 336–350, https://doi.org/https://doi.org/10.1016/j.marpolbul.2017.04.010, 2017b.

Addamo, A. M., Laroche, P., and Hanke, G.: Top marine beach litter items in Europe, Publ. Off. Eur. Union Luxembg., 2017.

Aksamit, N. O., Sapsis, T., and Haller, G.: Machine-Learning Mesoscale and Submesoscale Surface Dynamics from Lagrangian Ocean Drifter Trajectories, J. Phys. Oceanogr., 50, 1179–1196, https://doi.org/10.1175/jpo-d-19-0238.1, 2020.

Al-Zawaidah, H., Ravazzolo, D., and Friedrich, H.: Macroplastics in rivers: present knowledge, issues and challenges, Environ. Sci. Process. Impacts, 23, 535–552, https://doi.org/10.1039/d0em00517g, 2021.

Allshouse, M. R., Ivey, G. N., Lowe, R. J., Jones, N. L., Beegle-Krause, C. J., Xu, J., and Peacock, T.: Impact of windage on ocean surface Lagrangian coherent structures, Environ. Fluid Mech., 17, 473–483, https://doi.org/10.1007/s10652-016-9499-3, 2017.

Andrés, M., Delpey, M., Ruiz, I., Declerck, A., Sarrade, C., Bergeron, P., and Basurko, O. C.: Measuring and comparing solutions for floating marine litter removal: Lessons learned in the south-east coast of the Bay of Biscay from an economic perspective, Mar. Policy, 127, 104450, https://doi.org/https://doi.org/10.1016/j.marpol.2021.104450, 2021.

ASCE: State-of-the-Art Review of Modeling Transport and Fate of Oil Spills, J. Hydraul. Eng., 122, 594–609, https://doi.org/10.1061/(ASCE)0733-9429(1996)122:11(594), 1996.

Bilbao-Lasa, P., Jara-Muñoz, J., Pedoja, K., Álvarez, I., Aranburu, A., Iriarte, E., and Galparsoro, I.: Submerged Marine Terraces Identification and an Approach for Numerical Modeling the Sequence Formation in the Bay of Biscay (Northeastern Iberian Peninsula), Front. Earth Sci., 8, https://doi.org/10.3389/feart.2020.00047, 2020.

Blettler, M. C. M., Abrial, E., Khan, F. R., Sivri, N., and Espinola, L. A.: Freshwater plastic pollution: Recognizing research biases and identifying knowledge gaps, Water Res., 143, 416–424, https://doi.org/https://doi.org/10.1016/j.watres.2018.06.015, 2018.

Bourillet, J. F., Zaragosi, S., and Mulder, T.: The French Atlantic margin and deep-sea submarine systems, Geo-Marine Lett., 26, 311–315, https://doi.org/10.1007/s00367-006-0042-2, 2006.

Le Boyer, A., Charria, G., Le Cann, B., Lazure, P., and Marié, L.: Circulation on the shelf and the upper slope of the Bay of Biscay, Cont. Shelf Res., 55, 97–107, 2013.

Brennan, E., Wilcox, C., and Hardesty, B. D.: Connecting flux, deposition and resuspension in coastal debris surveys, Sci. Total Environ., 644, 1019–1026, https://doi.org/10.1016/J.SCITOTENV.2018.06.352, 2018.

Bruge, A., Barreau, C., Carlot, J., Collin, H., Moreno, C., and Maison, P.: Monitoring Litter Inputs from the Adour River (Southwest France) to the Marine Environment, Mar. Sci. Eng., 6(1), 24, https://doi.org/10.3390/jmse6010024, 2018.

C3S: ERA5: Fifth Generation of ECMWF Atmospheric Reanalyses of the Global Climate., https://cds.climate.copernicus.eu/cdsapp#!/home, 2019.

Callies, U., Groll, N., Horstmann, J., Kapitza, H., Klein, H., Maßmann, S., and Schwichtenberg, F.: Surface drifters in the German Bight: model validation considering windage and Stokes drift, Ocean Sci., 13, 799–827, https://doi.org/10.5194/os-13-799-2017, 2017.

Carlson, D. F., Pavalko, W. J., Petersen, D., Olsen, M., and Hass, A. E.: Maker Buoy Variants for Water Level Monitoring and Tracking Drifting Objects in Remote Areas of Greenland, 20, 1254, 2020.

Carson, H. S., Lamson, M. R., Nakashima, D., Toloumu, D., Hafner, J., Maximenko, N., and McDermid, K. J.: Tracking the sources and sinks of local marine debris in Hawai ‘i, Mar. Environ. Res., 84, 76–83, 2013.

Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel, S., Batifoulier, F., Dumas, F., Pichon, A., and Morel, Y.: Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay, J. Mar. Syst., 109, 60, https://doi.org/10.1016/j.jmarsys.2011.09.015, 2013.

Chiri, H., Abascal, A. J., Castanedo, S., and Medina, R.: Mid-long term oil spill forecast based on logistic regression modelling of met-ocean forcings, Mar. Pollut. Bull., 146, 962–976, https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.07.053, 2019.

Chiri, H., Abascal, A. J., and Castanedo, S.: Deep oil spill hazard assessment based on spatio-temporal met-ocean patterns, Mar. Pollut. Bull., 154, 111123, https://doi.org/10.1016/J.MARPOLBUL.2020.111123, 2020.

Compa, M., Alomar, C., Morató, M., Álvarez, E., and Deudero, S.: Spatial distribution of macro- and micro-litter items along rocky and sandy beaches of a Marine Protected Area in the western Mediterranean Sea, Mar. Pollut. Bull., 178, 113520, https://doi.org/10.1016/J.MARPOLBUL.2022.113520, 2022.

Critchell, K. and Lambrechts, J.: Modelling accumulation of marine plastics in the coastal zone; what are the dominant physical processes?Â , Estuar. Coast. Shelf Sci., 171, 111, 2016.

Critchell, K., Grech, A., Schlaefer, J., Andutta, F. P., Lambrechts, J., Wolanski, E., and Hamann, M.: Modelling the fate of marine debris along a complex shoreline: Lessons from the Great Barrier Reef, Estuar. Coast. Shelf Sci., 167, 414–426, https://doi.org/10.1016/J.ECSS.2015.10.018, 2015.

D’Asaro, E. A., Carlson, D. F., Chamecki, M., Harcourt, R. R., Haus, B. K., Fox-Kemper, B., Molemaker, M. J., Poje, A. C., and Yang, D.: Advances in Observing and Understanding Small-Scale Open Ocean Circulation During the Gulf of Mexico Research Initiative Era, Front. Mar. Sci., 7, https://doi.org/10.3389/fmars.2020.00349, 2020.

Dagestad, K.-F. and Röhrs, J.: Prediction of ocean surface trajectories using satellite derived vs. modeled ocean currents, Remote Sens. Environ., 223, 130–142, https://doi.org/https://doi.org/10.1016/j.rse.2019.01.001, 2019.

Davila, X., Rubio, A., Artigas, L. F., Puillat, I., Manso-Narvarte, I., Lazure, P., and Caballero, A.: Coastal submesoscale processes and their effect on phytoplankton distribution in the southeastern Bay of Biscay, Ocean Sci., 17, 849–870, https://doi.org/10.5194/os-17-849-2021, 2021.

Declerck, A., Delpey, M., Rubio, A., Ferrer, L., Basurko, O. C., Mader, J., and Louzao, M.: Transport of floating marine litter in the coastal area of the south-eastern Bay of Biscay: A Lagrangian approach using modelling and observations, J. Oper. Oceanogr., 1–15, https://doi.org/10.1080/1755876x.2019.1611708, 2019.

Delpey, M., Declerck, A., Epelde, I., Voirand, T., Manso-Navarte, I., Mader, J., Rubio, A., and Caballero, A.: Tracking floating marine litter in the coastal area by combining operational ocean modelling and remote observation systems., EGU Gen. Assem. 2021, online, 19–30 Apr 2021, EGU21-11465, 2021.

Duhec, A. V, Jeanne, R. F., Maximenko, N., and Hafner, J.: Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles, Mar. Pollut. Bull., 96, 76–86, https://doi.org/https://doi.org/10.1016/j.marpolbul.2015.05.042, 2015.

Duncan, E. M., Davies, A., Brooks, A., Chowdhury, G. W., Godley, B. J., Jambeck, J., Maddalene, T., Napper, I., Nelms, S. E., Rackstraw, C., and Koldewey, H.: Message in a bottle: Open source technology to track the movement of plastic pollution, PLoS One, 15, e0242459, https://doi.org/10.1371/journal.pone.0242459, 2020.

van Emmerik, T. and Schwarz, A.: Plastic debris in rivers, 7, e1398, https://doi.org/https://doi.org/10.1002/wat2.1398, 2020.

Fazey, F. M. C. and Ryan, P. G.: Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity, Environ. Pollut., 210, 354–360, https://doi.org/10.1016/J.ENVPOL.2016.01.026, 2016.

Ferrer, L. and Pastor, A.: The Portuguese man-of-war: Gone with the wind, Reg. Stud. Mar. Sci., 14, 53–62, https://doi.org/https://doi.org/10.1016/j.rsma.2017.05.004, 2017.

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

Gasperi, J., Dris, R., Bonin, T., Rocher, V., and Tassin, B.: Assessment of floating plastic debris in surface water along the Seine River, Environ. Pollut., 195, 163–166, https://doi.org/https://doi.org/10.1016/j.envpol.2014.09.001, 2014.

González-Fernández, D. and Hanke, G.: Toward a Harmonized Approach for Monitoring of Riverine Floating Macro Litter Inputs to the Marine Environment, Front. Mar. Sci., 4, https://doi.org/10.3389/fmars.2017.00086, 2017.

González-Fernández, D., Cózar, A., Hanke, G., Viejo, J., Morales-Caselles, C., Bakiu, R., Barceló, D., Bessa, F., Bruge, A., Cabrera, M., Castro-Jiménez, J., Constant, M., Crosti, R., Galletti, Y., Kideys, A. E., Machitadze, N., Pereira de Brito, J., Pogojeva, M., Ratola, N., Rigueira, J., Rojo-Nieto, E., Savenko, O., Schöneich-Argent, R. I., Siedlewicz, G., Suaria, G., and Tourgeli, M.: Floating macrolitter leaked from Europe into the ocean, Nat. Sustain., 4, 474–483, https://doi.org/10.1038/s41893-021-00722-6, 2021.

Gonzalez Fernandez, D., Hanke, G., Kideys, A., Navarrao Ortega, A., Sanchez Vidal, A., Bruge, A., Öztürk, B., Palma, C., Santelli, C., Duijsings, D., Barcelo, D., Dimitiriu, E., Rojo-Nieto, E., Ferreira, F., Bessa, F., Suaria, G., Siedlewicz, G., Castro Jimenez, J., Germano, J., Pereira De Brito, J., Rigueira, J., Pazdro, K., Cabrera, M., Pogojeva, M., Köck Schulmeyer, M., Constant, M., Canals Artigas, M., Paraboschi, M., Tourgeli, M., Machitadze, N., Ratola, N., Savenko, O., Kerherve, P., Sempere, R., Bakiu, R., Crosti, R., Schoeneich-Argent, R., Landry Levesque, S., Agostinho, T., Segal, Y., and Galletti, Y.: Floating Macro Litter in European Rivers - Top Items, EUR 29383 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-96373-5, doi:10.2760/316058, Luxembourg, https://doi.org/10.2760/316058, 2018.

González, M., Valencia, V., Mader, J., Fontán, A., Uriarte, A., and Caballero, A.: Operational Coastal Systems in the Basque Country Region: Modelling and Observations, Proc. Int. Offshore Polar Eng. Conf., 2007.

Haza, A. C., Paldor, N., Özgökmen, T. M., Curcic, M., Chen, S. S., and Jacobs, G.: Wind-Based Estimations of Ocean Surface Currents From Massive Clusters of Drifters in the Gulf of Mexico, J. Geophys. Res. Ocean., 124, 5844–5869, https://doi.org/https://doi.org/10.1029/2018JC014813, 2019.

Hoenner, X., Barlian, E., Ernawati, T., Hardesty, B. D., Kembaren, D. D., Mous, P. J., Sadiyah, L., Satria, F., and Wilcox, C.: Using anti-theft tracking devices to infer fishing vessel activity at sea, Fish. Res., 249, 106230, https://doi.org/https://doi.org/10.1016/j.fishres.2022.106230, 2022.

Hohn, S., Acevedo-Trejos, E., Abrams, J. F., Fulgencio de Moura, J., Spranz, R., and Merico, A.: The long-term legacy of plastic mass production, Sci. Total Environ., 746, 141115, https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.141115, 2020.

ICES: Bay of Biscay and the Iberian Coast Ecoregion – Ecosystem overview, ICES Ecosystem Overviews, 1–14 pp., 2019.

Kaplan, D. M. and Lekien, F.: Spatial interpolation and filtering of surface current data based on open-boundary modal analysis, J. Geophys. Res. Ocean., 112, https://doi.org/https://doi.org/10.1029/2006JC003984, 2007.

Karagiorgos, J., Vervatis, V., and Sofianos, S.: The Impact of Tides on the Bay of Biscay Dynamics, J. Mar. Sci. Eng., 8, 617, 2020.

Ko, C.-Y., Hsin, Y.-C., and Jeng, M.-S.: Global distribution and cleanup opportunities for macro ocean litter: a quarter century of accumulation dynamics under windage effects, Environ. Res. Lett., 15, 104063, https://doi.org/10.1088/1748-9326/abae29, 2020.

Kooi, M., Nes, E. H. van, Scheffer, M., and Koelmans, A. A.: Ups and Downs in the Ocean: Effects of Biofouling on Vertical Transport of Microplastics, Environ. Sci. Technol., 51, 7963–7971, https://doi.org/10.1021/acs.est.6b04702, 2017.

Lavin, A., Valdés, L., Sanchez, F., Abaunza, P., Forest, A., Boucher, J., Lazure, P., and Jegou, A.-M.: The Bay of Biscay: the encountering of the Ocean and the Shelf (18b, E), Combridge, MA, Harvard University Press, 2006.

Lebreton, L., Egger, M., and Slat, B.: A global mass budget for positively buoyant macroplastic debris in the ocean, Sci. Rep., 9, 1, 2019.

Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., and Reisser, J.: River plastic emissions to the world's oceans, Nat. Commun., 8, 15611, https://doi.org/10.1038/ncomms15611, 2017.

Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., Glas, M., and Schludermann, E.: The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river, Environ. Pollut., 188, 177–181, https://doi.org/10.1016/J.ENVPOL.2014.02.006, 2014.

Maclean, K., Weideman, E. A., Perold, V., and Ryan, P. G.: Buoyancy affects stranding rate and dispersal distance of floating litter entering the sea from river mouths, Mar. Pollut. Bull., 173, 113028, https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.113028, 2021.

Mai, L., Sun, X., Xia, L.-L., Bao, L.-J., Liu, L.-Y., and Zeng, E. Y.: Global Riverine Plastic Outflows, Environ. Sci. Technol., 2020.

Manso-Narvarte, I., Caballero, A., Rubio, A., Dufau, C., and Birol, F.: Joint analysis of coastal altimetry and high-frequency (HF) radar data: Observability of seasonal and mesoscale ocean dynamics in the Bay of Biscay, Ocean Sci., 14, 1265–1281, https://doi.org/10.5194/os-14-1265-2018, 2018.

Manso-Narvarte, I., Rubio, A., Jordà, G., Carpenter, J., Merckelbach, L., and Caballero, A.: Three-Dimensional Characterization of a Coastal Mode-Water Eddy from Multiplatform Observations and a Data Reconstruction Method, Remote Sens., 13, 674, https://doi.org/10.3390/rs13040674, 2021.

Margenat, H., Ruiz-Orejón, L. F., Cornejo, D., Martí, E., Vila, A., Le Roux, G., Hansson, S., and Guasch, H.: Guidelines of field-tested procedures and methods for monitoring plastic litter in Mountain riverine systems, 2021.

Marta-Almeida, M., Ruiz-Villarreal, M., Pereira, J., Otero, P., Cirano, M., Zhang, X., and Hetland, R. D.: Efficient tools for marine operational forecast and oil spill tracking, Mar. Pollut. Bull., 71, 139–151, https://doi.org/10.1016/J.MARPOLBUL.2013.03.022, 2013.

Martínez Fernández, A., Redondo Caride, W., Alonso Pérez, F., Piedracoba Varela, S., Lorente Jiménez, P., Montero Vilar, P., Torres López, S., Fernández Baladrón, A., Varela Benvenuto, R. A., and Velo Lanchas, A.: SPOT and GPRS drifting buoys for HF Radar calibration, Instrum. Viewp., 48–49, 2021.

Maximenko, N., Hafner, J., Kamachi, M., and MacFadyen, A.: Numerical simulations of debris drift from the Great Japan Tsunami of 2011 and their verification with observational reports, Mar. Pollut. Bull., 132, 5, 2018.

Mazarrasa, I., Puente, A., Núñez, P., García, A., Abascal, A. J., and Juanes, J. A.: Assessing the risk of marine litter accumulation in estuarine habitats, Mar. Pollut. Bull., 144, 117–128, https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.04.060, 2019.

Meijer, L. J. J., Emmerik, T. van, Ent, R. van der, Schmidt, C., and Lebreton, L.: More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean, Sci. Adv., 7, eaaz5803, https://doi.org/doi:10.1126/sciadv.aaz5803, 2021.

Melvin, J., Bury, M., Ammendolia, J., Charles, M., and Liboiron, M.: Critical Gaps in Shoreline Plastics Pollution Research, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.689108, 2021.

Meyerjürgens, J., Badewien, T. H., Garaba, S. P., Wolff, J.-O., and Zielinski, O.: A State-of-the-Art Compact Surface Drifter Reveals Pathways of Floating Marine Litter in the German Bight, Front. Mar. Sci., 6, https://doi.org/10.3389/fmars.2019.00058, 2019a.

Meyerjürgens, J., Badewien, T. H., Zielinski, O., Braun, A., and Butter, M.: Track of GPS-Drifter North_Sea_Drifter7 in the German Bight, Southern North Sea, https://doi.pangaea.de/10.1594/PANGAEA.897995, 2019b.

Min, K., Cuiffi, J. D., and Mathers, R. T.: Ranking environmental degradation trends of plastic marine debris based on physical properties and molecular structure, Nat. Commun., 11, 727, https://doi.org/10.1038/s41467-020-14538-z, 2020.

Mínguez, R., Abascal, • A J, Castanedo, • S, and Medina, • R: Stochastic Lagrangian trajectory model for drifting objects in the ocean, Stoch. Environ. Res. Risk Assess., 26, 1081–1093, https://doi.org/10.1007/s00477-011-0548-7, 2012.

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J. I., Montero, E., Arroyo, G. M., Hanke, G., Salvo, V. S., Basurko, O. C., Mallos, N., Lebreton, L., Echevarría, F., van Emmerik, T., Duarte, C. M., Gálvez, J. A., van Sebille, E., Galgani, F., García, C. M., Ross, P. S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., and Cózar, A.: An inshore–offshore sorting system revealed from global classification of ocean litter, Nat. Sustain., 4, 484–493, https://doi.org/10.1038/s41893-021-00720-8, 2021.

NOAA: Modeling Oceanic Transport of Floating Marine Debris, National Oceanic and Atmospheric Administration Marine Debris Program, 21 pp., 2016.

Novelli, G., Guigand, C. M., Cousin, C., Ryan, E. H., Laxague, N. J. M., Dai, H., Haus, B. K., and Özgökmen, T. M.: A Biodegradable Surface Drifter for Ocean Sampling on a Massive Scale, J. Atmos. Ocean. Technol., 34, 2509–2532, https://doi.org/10.1175/jtech-d-17-0055.1, 2017.

Novelli, G., Guigand, C. M., and Özgökmen, T. M.: Technological Advances in Drifters for Oil Transport Studies, Mar. Technol. Soc. J., 52, 53–61, https://doi.org/10.4031/mtsj.52.6.9, 2018.

Núñez, P., García, A., Mazarrasa, I., Juanes, J. A., Abascal, A. J., Méndez, F., Castanedo, S., and Medina, R.: A methodology to assess the probability of marine litter accumulation in estuaries, Mar. Pollut. Bull., 144, 309–324, https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.04.077, 2019.

Ocio, D., Stocker, C., Eraso, A., and Cowpertwait, P.: Regionalized extreme flows by means of stochastic storm generation coupled with a distributed hydrological model. The case of the Basque Country., Proc. 36th IAHR World Congr. 28 June – 3 July, 2015., 1–13, https://doi.org/10.13140/RG.2.1.3924.4889, 2015.

Pereiro, D., Souto, C., and Gago, J.: Calibration of a marine floating litter transport model, J. Oper. Oceanogr., 11, 125–133, https://doi.org/10.1080/1755876x.2018.1470892, 2018.

Pereiro, D., Souto, C., and Gago, J.: Dynamics of floating marine debris in the northern Iberian waters: A model approach, J. Sea Res., 144, 57–66, https://doi.org/https://doi.org/10.1016/j.seares.2018.11.007, 2019.

Porter, M., Inall, M. E., Green, J. A. M., Simpson, J. H., Dale, A. C., and Miller, P. I.: Drifter observations in the summer time Bay of Biscay slope current, J. Mar. Syst., 157, 65–74, 2016.

Puillat, I., Lazure, P., Anne-marie, J., Lampert, L., and Miller, P.: Mesoscale hydrological variability induced by northwesterly wind on the French continental shelf of the Bay of Biscay, Sci. Mar. (Institut Ciències del Mar Barcelona, CSIC), 2006-06 , Vol. 70 , N. 1 , P. 15-26, 70, 2006.

Putman, N. F., Lumpkin, R., Olascoaga, M. J., Trinanes, J., and Goni, G. J.: Improving transport predictions of pelagic Sargassum, J. Exp. Mar. Bio. Ecol., 529, 151398, https://doi.org/https://doi.org/10.1016/j.jembe.2020.151398, 2020.

Reed, M., Turner, C., and Odulo, A.: The role of wind and emulsification in modelling oil spill and surface drifter trajectories, Spill Sci. Technol. Bull., 1, 143–157, https://doi.org/10.1016/1353-2561(94)90022-1, 1994.

Révelard, A., Reyes, E., Mourre, B., Hernández-Carrasco, I., Rubio, A., Lorente, P., Fernández, C. D. L., Mader, J., Álvarez-Fanjul, E., and Tintoré, J.: Sensitivity of Skill Score Metric to Validate Lagrangian Simulations in Coastal Areas: Recommendations for Search and Rescue Applications, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.630388, 2021.

Rizal, A., Gautama, B. G., Pranowo, W. S., Farhan, A. R., Siong, K., Harjono, M. R., Voisin, J. B., Maes, C., Dobler, D., Berlianty, D., Priyono, B., Dufau, C., Lucas, M., Fauny, O., and Rahmania, R.: Tracking the Stranded Area of Marine Debris in Indonesian coasts by using Floating Drifter, IOP Conf. Ser. Earth Environ. Sci., 925, 12034, https://doi.org/10.1088/1755-1315/925/1/012034, 2021.

Robbe, E., Woelfel, J., Arūnas Balčiūnas, •, and Schernewski, • Gerald: An Impact Assessment of Beach Wrack and Litter on Beach Ecosystem Services to Support Coastal Management at the Baltic Sea, Environ. Manage., 68, 835–859, https://doi.org/10.1007/s00267-021-01533-3, 2021.

Rodríguez-Díaz, L., Gómez-Gesteira, J. L., Costoya, X., Gómez-Gesteira, M., and Gago, J.: The Bay of Biscay as a trapping zone for exogenous plastics of different sizes, J. Sea Res., 163, 101929, https://doi.org/https://doi.org/10.1016/j.seares.2020.101929, 2020.

Rodríguez, J. G., Garmendia, J. M., Muxika, I., Gómez-Ballesteros, M., Quincoces, I., Díez, I., Arrese, B., Sánchez, F., and Galparsoro, I.: Macrofaunal variability in the continental shelf and canyons in the southeastern Bay of Biscay, Reg. Stud. Mar. Sci., 48, 102012, https://doi.org/https://doi.org/10.1016/j.rsma.2021.102012, 2021.

Rubio, A., Reverdin, G., Fontán, A., González, M., and Mader, J.: Mapping near-inertial variability in the SE Bay of Biscay from HF radar data and two offshore moored buoys, Geophys. Res. Lett., 38, 1–6, https://doi.org/10.1029/2011GL048783, 2011.

Rubio, A., Solabarrieta, L., Gonzalez, M., Mader, J., Castanedo, S., Medina, R., Charria, G., and Aranda, J. A.: Surface circulation and Lagrangian transport in the SE Bay of Biscay from HF radar data, Ocean. 2013 MTS/IEEE Bergen Challenges North. Dimens., https://doi.org/10.1109/OCEANS-Bergen.2013.6608039, 2013.

Rubio, A., Mader, J., Corgnati, L., Mantovani, C., Griffa, A., Novellino, A., Quentin, C., Wyatt, L., Schulz-Stellenfleth, J., Horstmann, J., Lorente, P., Zambianchi, E., Hartnett, M., Fernandes, C., Zervakis, V., Gorringe, P., Melet, A., and Puillat, I.: HF Radar Activity in European Coastal Seas: Next Steps toward a Pan-European HF Radar Network, Front. Mar. Sci., 4, https://doi.org/10.3389/fmars.2017.00008, 2017.

Rubio, A., Caballero, A., Orfila, A., Hernández-Carrasco, I., Ferrer, L., González, M., Solabarrieta, L., and Mader, J.: Eddy-induced cross-shelf export of high Chl-a coastal waters in the SE Bay of Biscay, Remote Sens. Environ., 205, 290–304, https://doi.org/https://doi.org/10.1016/j.rse.2017.10.037, 2018.

Rubio, A., Hernández-Carrasco, I., Orfila, A., González, M., Reyes, E., Corgnati, L., Berta, M., Griffa, A., and Mader, J.: A Lagrangian approach to monitor local particle retention conditions in coastal areas, J. Oper. Oceanogr., 13:sup1, https://doi.org/10.1080/1755876X.2020.1785097, 2020.

Rubio, A., Solabarrieta, L., Corgnati, L., Mantovani, C. Reyes, E., Rotllan-García, P., Novellino, A., Gorringe, P., Griffa, A., and Mader, J.: Building a reliable and standardized long-term data set of surface coastal ocean currents from the european hf radarsconstruction d'un ensemble de données à long terme fiables et normalisées sur les courants océaniques côtiers de surface à partir des rad,, in: 9th EuroGOOS International conference, Breakout session 8 : Data Management and MetrologyEnvironmental SciencesConference papersavec comité de lecture, 338–346, 2021.

Ruiz, I., Basurko, O. C., Rubio, A., Delpey, M., Granado, I., Declerck, A., Mader, J., and Cózar, A.: Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter, Front. Mar. Sci., 7, https://doi.org/10.3389/fmars.2020.00308, 2020a.

Ruiz, I., Basurko, O. C., Epelde, I., Liria, P., Rubio, AnnaMader, J., and Delpey, M.: Monitoring floating riverine pollution by advanced technology Monitoring floating riverine pollution by advanced technology, 22613, 2020b.

Ruiz, I., Abascal, A. J., Basurko, O. C., and Rubio, A.: Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas, Environ. Pollut., 292, 118216, https://doi.org/https://doi.org/10.1016/j.envpol.2021.118216, 2022.

Russell, K.: Spain's Coastal Authority Uses Spot Trace for Search and Rescue Training, https://www.satellitetoday.com/telecom/2017/06/20/spains-coastal-authority-uses-spot-trace-search-rescue-training/, 2017.

Ryan, P. G.: Does size and buoyancy affect the long-distance transport of floatingdebris?Â , Environ. Res. Lett., 10, 1, 2015.

Schmidt, C., Krauth, T., and Wagner, S.: Export of Plastic Debris by Rivers into the Sea, Environ. Sci. Technol., 51, 12246–12253, https://doi.org/10.1021/acs.est.7b02368, 2017.

Schuyler, Q., Wilcox, C., Lawson, T. J., M K P Ranatunga, R. R., Hu, C.-S., Plastics Project Partners, G., and Denise Hardesty, B.: Human Population Density is a Poor Predictor of Debris in the Environment, Front. Environ. Sci., 9, https://doi.org/10.3389/fenvs.2021.583454, 2021.

van Sebille, E., Zettler, E., Wienders, N., Amaral-Zettler, L., Elipot, S., and Lumpkin, R.: Dispersion of Surface Drifters in the Tropical Atlantic, Front. Mar. Sci., 7, https://doi.org/10.3389/fmars.2020.607426, 2021.

Van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J. M., Bagaev, A., Bergmann, M., Chapron, B., Chubarenko, I., and Cózar, A.: The physical oceanography of the transport of floating marine debris, Environ. Res. Lett., 15, 23003, 2020.

Sheppard, C.: World Seas: An Environmental Evaluation: Volume I: Europe, The Americas and West Africa, 2018.

Solabarrieta, L., Rubio, A., Castanedo, S., Medina, R., Charria, G., and Hernández, C.: Surface water circulation patterns in the southeastern Bay of Biscay: New evidences from HF radar data, Cont. Shelf Res., 74, 60–76, https://doi.org/https://doi.org/10.1016/j.csr.2013.11.022, 2014.

Solabarrieta, L., Rubio, A., Cárdenas, M., Castanedo, S., Esnaola, G., Méndez, F. J., Medina, R., and Ferrer, L.: Probabilistic relationships between wind and surface water circulation patterns in the SE Bay of Biscay, Ocean Dyn., 65, 1289–1303, https://doi.org/10.1007/s10236-015-0871-5, 2015.

Solabarrieta, L., Frolov, S., Cook, M., Paduan, J., Rubio, A., González, M., Mader, J., and Charria, G.: Skill Assessment of HF Radar–Derived Products for Lagrangian Simulations in the Bay of Biscay, J. Atmos. Ocean. Technol., 33, 2585–2597, https://doi.org/10.1175/jtech-d-16-0045.1, 2016.

Solabarrieta, L., Hernández-Carrasco, I., Rubio, A., Campbell, M., Esnaola, G., Mader, J., Jones, B. H., and Orfila, A.: A new Lagrangian-based short-term prediction methodology for high-frequency (HF) radar currents, Ocean Sci., 17, 755–768, https://doi.org/10.5194/os-17-755-2021, 2021.

Stanev, E. V, Badewien, T. H., Freund, H., Grayek, S., Hahner, F., Meyerjürgens, J., Ricker, M., Schöneich-Argent, R. I., Wolff, J. O., and Zielinski, O.: Extreme westward surface drift in the North Sea: Public reports of stranded drifters and Lagrangian tracking, Cont. Shelf Res., 177, 24–32, https://doi.org/https://doi.org/10.1016/j.csr.2019.03.003, 2019.

Teles-Machado, A., Peliz, Á., McWilliams, J. C., Dubert, J., and Cann, B. Le: Circulation on the Northwestern Iberian Margin: Swoddies, Prog. Oceanogr., 140, 116–133, https://doi.org/10.1016/J.POCEAN.2015.09.011, 2016.

Tong, X., Jong, M.-C., Zhang, J., You, L., and Gin, K. Y.-H.: Modelling the spatial and seasonal distribution, fate and transport of floating plastics in tropical coastal waters, J. Hazard. Mater., 414, 125502, https://doi.org/https://doi.org/10.1016/j.jhazmat.2021.125502, 2021.

Utenhove, E. van: Modelling the transport and fate of buoyant macroplastics in coastal waters, 2019.

van der Wal, M., van der Meulen, M., Tweehuijsen, G., Peterlin, M., Palatinus, A., Kovač Viršek, M., Coscia, L., and Kržan, A.: Identification and Assessment of Riverine Input of (Marine) Litter, Final Rep. Eur. Comm. DG Environ. under Framew. Contract No ENV.D.2/FRA/2012/0025, 1–208, 2015.

Weideman, E. A., Perold, V., Omardien, A., Smyth, L. K., and Ryan, P. G.: Quantifying temporal trends in anthropogenic litter in a rocky intertidal habitat, Mar. Pollut. Bull., 160, 111543, https://doi.org/10.1016/J.MARPOLBUL.2020.111543, 2020.

Wendt-Potthoff, K., Avellán, T., van Emmerik, T., Hamester, M., Kirschke, S., Kitover, D., and Schmidt, C.: Monitoring Plastics in Rivers and Lakes: Guidelines for the Harmonization of Methodologies, 2020.

Widyatmoko, A. C., Hardesty, B. D., and Wilcox, C.: Detecting anchored fish aggregating devices (AFADs) and estimating use patterns from vessel tracking data in small-scale fisheries, Sci. Rep., 11, 17909, https://doi.org/10.1038/s41598-021-97227-1, 2021.

Supplementary material

Supplementary Figure 5.17

Supplementary Fig 5.17. Floating barrier for riverine litter collection.Floating barrier (a) and installation in Deba river (Gipuzkoa) (b).

Supplementary Table 5.9

Supplementary Table 5.9. Riverine litter classification based on the exposure to wind effect Data were gathered from surveys carried out during Spring 2018 in Deba river (Gipuzkoa).

TSG_ML General code	General name	Number of items	Weight (kg)
Low buoyant items transported by currents			
G1	4/6-pack yokes, six-pack rings	1	3.3
G2	Bags	7	170.7
G3	Shopping bags incl. pieces	8	292.44
G4	Small plastic bags, e.g freezer bags	4	50.9
G5	What remains form rip-off plastic bags	21	186.31
G20-G24	Plastic caps and lids/Plastic rings	38	216.39
G26	Cigarrette lighters	1	9.7
G27	Cigarrette butts and filters	1	0.1
G30	Crisps packets/sweet wrappers	56	250.2
G31	Lolly sticks	1	2.4
G32	Toys and party poppers	2	97.5
G36	Fertilisers/animal feed bags	1	11.5
G48	Synthetic rope	2	6.7
G76	Plastic/polystyrene pieces 2.5 cm> < 50 cm	1122	1788.32
G77	Plastic/polystyrene > 50 cm	13	337.34
G96	Sanitary towels/panty liners/backing strips	35	1099.8
G100	Medical/Pharmaceutical containers/tubes	7	69.4

TSG_ML General code	General name	Number of items	Weight (kg)
Low buoyant items transported by currents			
G101	Dog faeces bag	2	106
G124	Other plastic/polystyrene items (identifiable)	58	1958.5
G125	Ballons and ballon sticks	5	1.1
G134	Other rubber pieces	1	1.6
G135	Clothing (clothes, shoes)	3	481.7
G145	Other textiles (incl. rags)	7	320.5
G148	Carboard (boxes & fragments)	3	85.7
G156-157	Paper & Paper fragments	2	121.2
G158	Other paper items	4	69.1
G159	Corks	4	21.2
G173	Other (specify)	21	99.3
G177	Foil wrappers, aluminium foil	1	7
G179	Bottle caps, lids & pull tabs	1	0
	Total	**91.12%**	**67.95%**
Highly buoyant items transported by wind and currents			
G7	Drink bottles <= 0.5 l	5	142.6
G8	Drink bottles > 0.5 l	3	91.1
G9	Cleaner bottles & containers	2	105.7
G10	Food containers incl. Fast food containers	98	723.9
G11-12	Cosmetics bottles & other containers (shampoo, shower gel, deodorant)	4	100.3
G17	Injection gun containers	1	18.3
G33	Cups and cup lids	6	32.6
G150-151	Cartons/Tetrapack	2	121.2
G153	Cups, food trays, food wrappers, drink containers	4	69.1
G174	Aerosol/Spray cans industry	2	143.2
G175-176	Bottle caps, lids & pull tabs	2	5
G177	Bottles incl.Pieces	5	1832.3
G178	Light bulbs	1	31.7
	Total	**8.88%**	**32.05 %**

Supplementary Table 5.10. Periods selected between 2009 and 2021 based on the availability surface current datasets provided by the HF radar.

Winter

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
Initial	07-Feb-2013	09-Mar-2021	23-Jan-2009	02-Jan-2013	18-Jan-2016	02-Jan-2014	17-Feb-2017	17-Jan-2012	22-Jan-2017	12-Jan-2021
date	08:00:00	22:00:00	01:00:00	11:00:00	17:00:00	15:00:00	06:00:00	09:00:00	17:00:00	23:00:00
Final	14-Feb-2013	16-Mar-2021	30-Jan-2009	09-Jan-2013	25-Jan-2016	09-Jan-2014	24-Feb-2017	24-Jan-2012	29-Jan-2017	19-Jan-2021
date	07:00:00	21:00:00	00:00:00	10:00:00	16:00:00	14:00:00	05:00:00	08:00:00	16:00:00	22:00:00

Spring

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
Initial	14-Apr-2015	16-May-2012	16-Apr-2017	21-Apr-2012	05-Jun-2014	11-Apr-2021	06-May-2012	10-Apr-2015	08-May-2018	22-Apr-2016
date	23:00:00	00:00:00	14:00:00	08:00:00	06:00:00	20:00:00	06:00:00	08:00:00	22:00:00	11:00:00
Final	21-Apr-2015	22-May-2012	23-Apr-2017	28-Apr-2012	12-Jun-2014	18-Apr-2021	13-May-2012	17-Apr-2015	15-May-2018	29-Apr-2016
date	22:00:00	23:00:00	13:00:00	07:00:00	05:00:00	19:00:00	05:00:00	07:00:00	21:00:00	10:00:00

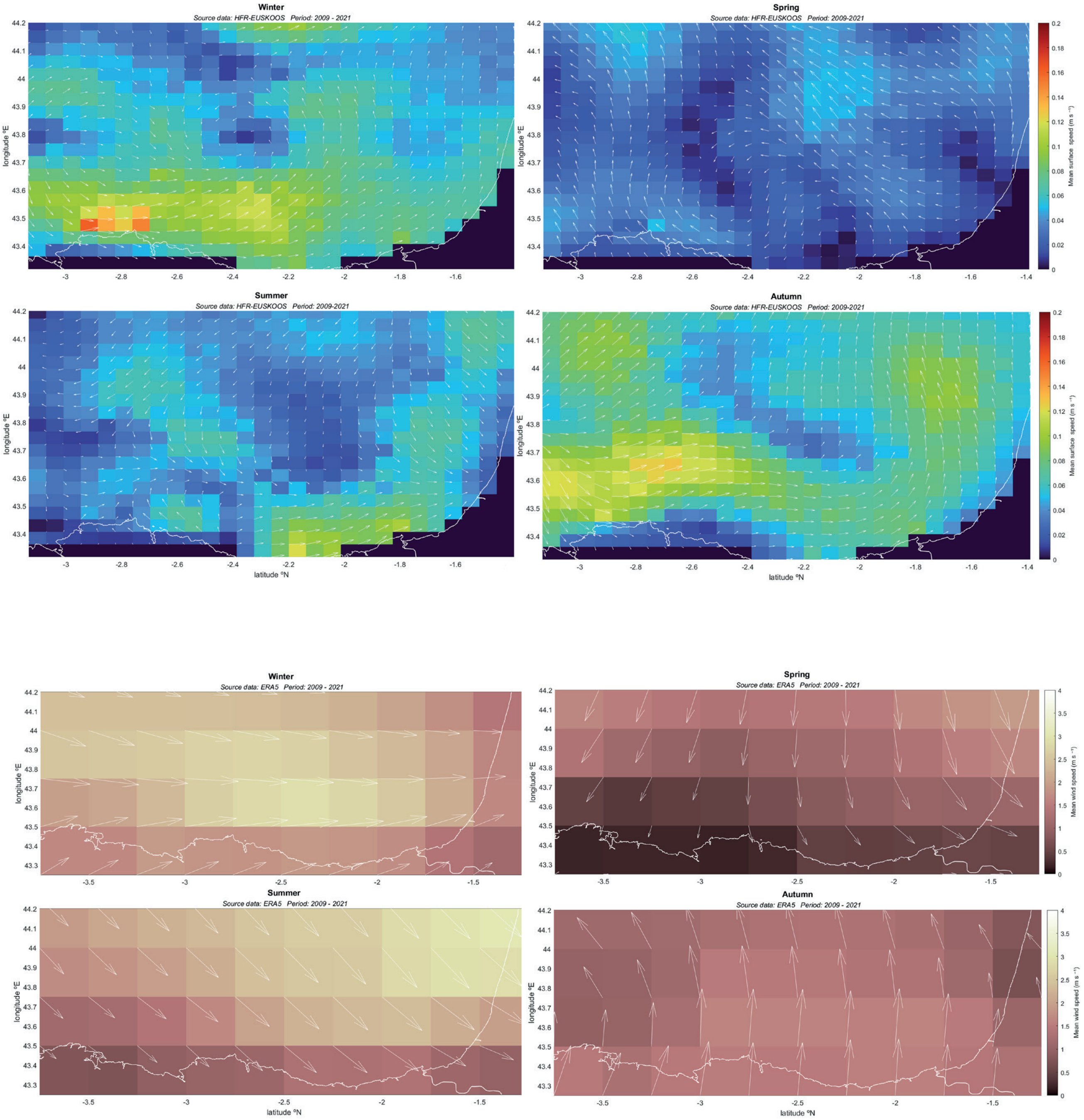
Summer

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
Initial	19-Aug-2017	04-Jul-2015	15-Aug-2016	08-Aug-2012	14-Aug-2015	08-Sep-2013	11-Sep-2017	13-Sep-2015	08-Jul-2019	05-Aug-2014
date	01:00:00	16:00	18:00:00	11:00:00	00:00:00	23:00:00	11:00:00	02:00:00	4:00	20:00:00
Final	26-Aug-2017	11-Jul-2015	22-Aug-2016	15-Aug-2012	20-Aug-2015	15-Sep-2013	18-Sep-2017	20-Sep-2015	15/-Jul-2019	12-Aug-2014
date	00:00:00	15:00	17:00:00	10:00:00	23:00:00	22:00:00	10:00:00	01:00:00	3:00	19:00:00

Autumn

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10
Initial	16-Oct-2014	17-Oct-2011	24-Oct-2015	08-Nov-2011	10-Dec-2020	06/11/2015	23-Nov-2015	04-Oct-2017	04-Oct-2015	23-Nov-2020
date	22:00	8:00	11:00	17:00:00	10:00:00	1:00	21:00:00	23:00:00	20:00:00	04:00:00
Final	23-Oct-2014	24-Oct-2011	31-Oct-2015	15-Nov-2011	17-Dec-2020	13/11/2015	30-Nov-2015	11-Oct-2017	11-Oct-2015	30-Nov-2020
date	21:00	7:00	10:00	16:00:00	09:00:00	0:00	20:00:00	22:00:00	19:00:00	03:00:00

Supplementary Figure 5.18



Supplementary Fig 5.18. Mean current (A) and wind fields (B) in the study area during each season for the selected periods between 2009 and 2021. The colour-bars represent the magnitude of current and wind speed. The arrows indicate the current and wind mean direction and are scaled with currents and wind speed (Data source: HFR – EuskOOS https://www.euskoos.eus/en/data/basque-ocean-meteorological-network/high-frequency-coastal-radars/ and ERA5 https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5).

6

DISCUSSION

The knowledge acquired in this research work aimed at providing new insights on the abundance, composition, distribution and fate of FML in the south-east Bay of Biscay. By crossing together the acquired knowledge in this thesis with the state of art outlined in the introduction section, the following reflections emerge as a way to contextualize the present and the future of the floating marine litter research in the region.

ABUNDANCE OF FLOATING MARINE LITTER IN THE BAY OF BISCAY, A MATTER OF SIZE

It is important to determine the abundance of marine litter in the ocean in order to effectively assess the ‘status’ of the marine environment and provide the most (cost) effective measures for prevent and mitigate marine pollution (GESAMP, 2019). To do so, monitoring the different ocean compartments, in particular, the sea surface, may provide reliable estimates of FML abundances and the corresponding changes in space and time. In the Bay of Biscay, long-term data on FML abundance are scarce, contrary to the substantial number of studies available for other European regions as the Mediterranean Sea (Lambert et al., 2020; Hatzonikolakis et al., 2022) or for persistent FML accumulation areas as the North Pacific sub-tropical gyre (Egger et al., 2021; Chen et al., 2018). Nevertheless, the sampling efforts performed in the Bay of Biscay on a regular basis between 2017 and 2020 provided initial measurements of micro, meso and macrolitter abundances at regional and sub-regional scale. Large difference on macrolitter abundances was observed between open and coastal waters. Such differences were expected since coastal sampling targeted “litter windrows”, which accumulate large FML loads (mean ± SD=24,864,714 ± 26,159,598 g/km2), while ocean water sampling was limited to visual observations from a vessel (mean ± SD=3.13 ± 2.46 items/km2).

Up to date, “litter windrows” have never been documented for the open waters of the Bay of Biscay because they were omitted from integrated ecosystem surveys set by different the sampling strategies occurring in the region. An appropriate evaluation of the status of floating macrolitter demands start recording the presence and FML abundance in “litter windrows” when monitoring at open waters. Besides, as revealed in the Results section, “litter windrows” do form in the south-east Bay of Biscay which represent a main mechanism for aggregating macrolitter. Hence, a greater sampling effort to capture the seasonal variations regarding their occurrence and loads in the area may support clean-up actions and management measures undertaken by the south-eastern coastal regions. This may consequently avoid the potential underestimation of the amount of FML in the south-east Bay of Biscay by only focusing on Neustonic samplings.

The circulation in the coastal area is highly complex and variable due to seasonal changes in river outputs, ocean currents and movement to and from other water compartments (GESAMP, 2019). This circulation has a directly impact on the abundance and distribution of FML and can provide an explanation for some of the spatial and temporal differences of macro and also microlitter abundances in the south-east Bay of Biscay. abundances observed in the French coast were 5 times higher when comparing to the neighbouring Spanish coasts (which were few km apart from each other).

The differences observed were less significant when comparing microlitter abundances recorded in the open (mean ± SD=756,865 ± 1,784,240 items/km2) against coastal waters of the Bay of Biscay (mean ± SD=1,117,403 ± 3,808,626 items/km2). These preliminary results outlined that both macrolitter and microlitter behaviour may varied significantly at regional and sub-regional scale as well as transboundary level. Despite the differences, microlitter abundances demonstrates that the south-east Bay of Biscay is a dead-end for plastic, comprising similar values to recorded in the Mediterranean Sea. However, further research is required to substantiate these results before drawing conclusions on FML abundances that may lead to biased.

COMPOSITION AND SOURCES OF FLOATING MACROLITTER IN THE BAY OF BISCAY: PACKAGING VERSUS FISHERIES

The analysis of the composition of marine litter is important as it provides vital information on individual litter items, which, in most cases, can be traced back to their sources (Galgani et al., 2015). However, identifying the origin of litter items is a difficult task and have an inherent degree of associated uncertainty, particularly for microlitter, which can originate from a number of sources and enter the ocean via different pathways (Veiga et al., 2016). In the open waters of the Bay of Biscay, “Plastic cover packaging items” tops the list of most abundant floating macrolitter items in terms of number. At global scale, packaging makes up the 15.9% of marine litter and most of plastic packaging waste is estimated to come from household (Schwarz et al., 2019; Geyer, 2020). Although is often stated that land-based sources represent a large percentage of marine litter, origin can vary widely across regions and sampling sites. Indeed, sea-based sources are sometimes dominant over land-based sources in some European basins, comprising an estimated average of 32%-50% of total marine litter found (Sherrington et al., 2016). In the south-east Bay of Biscay, fishing, shipping and aquaculture sectors were the source of the 35% of the floating macrolitter items analyzed by number (55% by weight). Results underline that sub-regional differences on FML composition and sources can occur. Variations can be motivated by (1) the different areas for surface sampling (coastal vs. open waters); (2) the spatial and temporal scales (submesoscale aggregation structures of FML (“litter windrows”) vs. the continental shelf of the Bay of Biscay); and (3) the selected sampling methodology (visual observations vs. towing a net). As a first attempt, results provided in this thesis describe floating macrolitter origin and composition in quantitative terms over specified time periods and for a delimited area of the Bay of Biscay. Nevertheless, there are still knowledge gaps to support management decisions, such as introducing restrictions on certain items, and to help in negotiating a reduction in trans-boundary sources. Repeated measurements both in open and coastal waters will help to describe the variability on the contribution from the existing sources within the region and may help to validate the composition and source proportions observed in this thesis.

WINDAGE AND SUB-MESOSCALE PROCESSES FOR TWO-SPEED FLOATING MARINE LITTER DISTRIBUTION AND FATE IN THE BAY OF BISCAY

Regular monitoring is necessary for assessing the extent and possible impact of marine litter on the environment, devising possible mitigation methods to reduce inputs, and evaluating the effectiveness of such measures (GESAMP, 2019). However, given the sparsity of observations, numerical simulations can be used to both ‘fill in the gaps’ between these observations, and to test hypotheses about how plastic particles behave in the ocean (Van Sebille et al., 2020). In this thesis, numerical simulations based on meteocean data, FML and drifters’ observations, and windage parametrizations were performed to estimate the distribution and fate of fishing-related and riverine litter items in the open waters and in the south-east coast Bay of Biscay. Results at regional and sub-regional scale demonstrated the windage effect has a strong impact of on the behaviour of FML. A wind drag (Cd) variation from 0 to 4% significantly altered the trajectories and fate of floating macrolitter. Highly buoyant items (Cd=4%) rapidly ended up in the coastal area, particularly during summer. Floating riverine litter items beached faster than fishing-related items due to their proximity to the coastal area, highlighting that the release location has important consequences on the pathways and final destination of FML. In contrast, fishing, and riverine items less exposed to wind effect remained floating for longer periods instead of becoming beached. Results also revealed that FML occurrence on the water surface and in the coastal regions of the Bay of Biscay was highly dependent on the seasonal circulations patterns. This circulation enhances FML retention in the Bay of Biscay despite the buoyancy of the item and the release location and strengthens the claims about the high exposure of the region to FML accumulation. The scenario combining highly buoyant items and onshore winds demands a quick response from stakeholders in the region, particularly to avoid the significant environmental impact of FML in French Marine Protected Areas (MPAs). Simulations also showed that regions in the south-east Bay of Biscay, in particular, Gipuzkoa and Pyrénées-Atlantiques were strong impacted by both riverine and fishing related items. As French MPAs, this area clearly requires more attention and cooperation at transboundary level to reduce the occurrence of FML.

As described in Results section, submesoscale convergence zones in the south-east Bay of Biscay aggregate FML as “litter windrows”. Future planned research operations in the area expected to give insights into submesoscale dynamics originating litter windrows. Mesoscale and open ocean processes responsible of FML estimates in the Bay of Biscay have not been identified yet neither correlation between micro and macrolitter abundances and oceanographic variables have been observed. Further focused monitoring and significant research effort is still required to better understand the physical processes that influence the transport, distribution and fate of FML on the surface waters of the region.

References

Chen, Q., Reisser, J., Cunsolo, S., Kwadijk, C., Kotterman, M., Proietti, M., Slat, B., Ferrari, F. F., Schwarz, A., Levivier, A., Yin, D., Hollert, H., and Koelmans, A. A.: Pollutants in Plastics within the North Pacific Subtropical Gyre, Environ. Sci. Technol., 52, 446–456, https://doi.org/10.1021/acs.est.7b04682, 2018.

Egger, M., Quiros, L., Leone, G., Ferrari, F., Boerger, C. M., and Tishler, M.: Relative Abundance of Floating Plastic Debris and Neuston in the Eastern North Pacific Ocean , https://www.frontiersin.org/article/10.3389/fmars.2021.626026, 2021.

Galgani, F., Hanke, G., and Maes, T.: Global Distribution, Composition and Abundance of Marine Litter, in: Marine Anthropogenic Litter, edited by: Bergmann, M., Gutow, L., and Klages, M., Springer International Publishing, Cham, 29–56, https://doi.org/10.1007/978-3-319-16510-3_2, 2015.

GESAMP: Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean, Journal Series GESAMP Reports and Studies, 123 pp., 2019.

Hatzonikolakis, Y., Giakoumi, S., Raitsos, D. E., Tsiaras, K., Kalaroni, S., Triantaphyllidis, G., and Triantafyllou, G.: Quantifying Transboundary Plastic Pollution in Marine Protected Areas Across the Mediterranean Sea , https://www.frontiersin.org/article/10.3389/fmars.2021.762235, 2022.

Lambert, C., Authier, M., Dorémus, G., Laran, S., Panigada, S., Spitz, J., Van Canneyt, O., and Ridoux, V.: Setting the scene for Mediterranean litterscape management: The first basin-scale quantification and mapping of floating marine debris, Environ. Pollut., 263, 114430, https://doi.org/https://doi.org/10.1016/j.envpol.2020.114430, 2020.

Van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J. M., Bagaev, A., Bergmann, M., Chapron, B., Chubarenko, I., and Cózar, A.: The physical oceanography of the transport of floating marine debris, Environ. Res. Lett., 15, 23003, 2020.

Sherrington, C., Darrah, C., Hann, S., Cole, G., and Corbin, M.: Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment, Eunomia, 2016.

Veiga, J. M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Galgani, F., Thompson, R. C., Dagevos, J., and Gago, J.: Identifying sources of marine litter. MSFD GES TG Marine Litter Thematic Report, JRC Technical Report. MSFD GES TG Marine Litter Thematic Report.EUR 28309., 2016.

7

CONCLUSION AND THESIS

CONCLUSIONS

The main objective of this research is described as:

“To improve the knowledge on the abundance, composition, distribution and fate of floating litter in the south-eastern Bay of Biscay by based on met-ocean historical data, visual marine litter and drifters observations, surface sampling, and Lagrangian modelling techniques.”

To meet this objective, four specific objectives were proposed. The main findings of this thesis are presented on the basis of these objectives below.

The first objective of this thesis was: “Assess the abundance and distribution of floating marine litter in the Bay of Biscay combining surface observations from vessels and sampling in open ocean and coastal waters of the south-eastern Bay of Biscay (Chapters 1 and 2)”. The main conclusions in relation to this objective are:

01. Data derived from monitoring FML, and the subsequent abundance analysis confirm that the region can be regarded, at least in spring-summer, as convergence area for FML.

02. In the open waters of the Bay of Biscay, visual observations of floating macrolitter (>2.5 cm) and microlitter sampling (<0.5 cm) reported an average of 3.13 items/km2 and 1,117,403 items/km2,respectively.

03. In the coastal area of the south-east of Bay of Biscay, the average microlitter abundance is slightly higher than in open waters (739,395 items/km2).

04. From a transboundary perspective, the abundance for meso and microlitter in French coast was 5 times higher when comparing to abundances in the Spanish coasts.

05. Packaging items (e.g., food wrappers) were the most abundant floating macro litter observed from vessel in the open waters (23.39%) while plastic fragments were the most abundant items collected in the south-east of Bay of Biscay from neustonic sampling.

06. No correlation was found between oceanographic variables neither macro nor microlitter abundances in the Bay of Biscay at large and mesoscale. However, a strong positive correlation was detected between micro and mesoplastic abundances in the south-east of Bay of Biscay.

The second objective of this thesis was: “Study the convergence zones of floating marine litter in the south-east coast of the Bay of Biscay (so-called “litter windrows”) through active fishing for litter activities to estimate their loads, composition, frequency, size, and potential sources (Chapter 3)”. The main conclusions in relation to this objective are:

07. Litter windrows derived from submesoscale prcesses are recurrent aggregation structures which concentrate macrolitter in an effective manner during Spring and Summer in the south-east Bay of Biscay.

06. Litter windrows were around 1 km length and, on average, accumulated 77.75 kg of FML. The average FML (dry) density per windrow was 24,864,714 ± 26,159,598 g/km2.

07. Fishing, shipping and aquaculture sectors were the source of the 35% of the litter items analyzed by number and 55% by weight.

08. Fishing for litter activities can be a useful scheme to clean-up aggregation areas of FML from the ocean surface where litter windrows occur. Besides, they have proven to be a good approach to assist in data collection to better understand the submesoscale processes origi nating litter windrows.

The third objective of this thesis was: “Analyze the seasonal pathways and fate of floating marine litter originated from sea-based activities in the Bay of Biscay as well as the concentration within Marine Protected Areas combining met-ocean and fishing activity databases, Monte Carlo simulations and Lagrangian modelling (Chapter 4)”. The main conclusions in relation to this objective are:

09. The behavioural differences over temporal scale demonstrate the impact of windage effect on FML transport and distribution in the Bay of Biscay.

10. Highly buoyant fishing-related items rapidly beached, mainly in summer, and were almost non-existent on the surface waters of the Bay of Biscay after 90 days from releasing. By contrast, half of low buoyant items remained floating after 90 days and only 20–35 % beached.

11. The highest concentrations occurred in French Marine Protected Areas (75 particles/km2 on average) mainly by the end of summer and during autum.

12. Less than a fifth of the fishing-related items released in the Bay of Biscay escaped from the basin which reinforced that the region acts as accumulation area for FML.

The fourth objective of this thesis was: “Analyze the seasonal pathways and fate of floating riverine litter transported through rivers to the south-east coast of the Bay of Biscay combining satellite-tracked observations provided by surface drifters, measurements of surface currents from high frequency radar systems and Lagrangian modelling (Chapter 5)”. The main conclusions in relation to this objective are:

13. The regions in the south-east Bay of Biscay were highly affected by floating riverine litter released by rivers within or nearby the region itself.

14. As in the case of highly buoyant fishing-related items, highly buoyant riverine litter items beached faster, particularly in summer and during the first 24 hours from releasing.

15. The lowest beaching rates occurred during Spring for low buoyant riverine litter items (<25% particles beached) and during Autumn for highly buoyant items (54% of beached).

16. Gipuzkoa and Pyrénées-Atlantiques were the regions in the south-east coast of the Bay of Biscay mostly affected by floating riverine litter (>200 particles/km).

THESIS

The results obtained in this thesis allowed working towards the validation of the enunciated working hypothesis, being the thesis that:

"*This thesis demonstrated that the behaviour of floating marine litter in the south-east Bay of Biscay is complex and variable, with circulation patterns on multiple scales in space and time controlling the transport, accumulation, and dispersion processes. These physical processes are responsible of aggregating floating marine litter as "litter windrows" at the submesoscale domain in the south-east Bay of Biscay. At larger scales, wind effect controls the behaviour of floating marine litter, highly impacting on the south-east coast of the Bay of Biscay and on French Marine Protected Areas. Abundances and composition revealed that the south-east Bay of Biscay is an accumulation area for microplastics, and fishing, shipping, and aquaculture sectors dominated macrolitter origin for litter windrows. Overall, these results may serve for prioritize interventions oriented to prevent and mitigate floating marine litter in the south-east Bay of Biscay but also at basin scale.*"

8

RECOMMENDATIONS FOR FUTURE ACTIONS AND RESEARCH

The outcomes of this thesis provide key data and facts to assess the state of FML in the south-east Bay of Biscay as well as information to outline prevention and mitigation measures at sub-regional and regional scale. Based on the findings of this study, recommendations for future actions and research needs are presented below summarized in three mainly targets: (1) Monitoring, (2) Modelling, and (3) Governance for floating litter in the Bay of Biscay and south-east Bay of Biscay.

TARGET 1: MONITORING FLOATING LITTER ABUNDANCE IN THE BAY OF BISCAY AND SOUTH-EAST BAY OF BISCAY

The quantities and the relative importance of different land- and sea-based sources of floating litter need to be explored in greater detail. Considering the regional and sub-regional differences, more detailed monitoring is required. It is recommended to:

» Encourage the continuity of integrated ecosystem surveys that already exist in open waters of the Bay of Biscay to build up a robust database and detect trends of FML in space and time. Data may also provide valuable information to feed indicators regarding the environmental status of the marine environment in the region.

» Develop a sampling strategy to quantify the amount of floating riverine litter being transported through rivers to the south-east Bay of Biscay. Data gathered may define a “baseline” or reference state of riverine pollution at sub-regional scale and determine whether rivers are major contributors to FML in the area.

» Promote the application of emerging and mature technologies to monitor floating litter abundances and pathways in the Bay of Biscay. This includes direct observations from e.g., drifting buoys and autonomous vehicles for tracking floating litter trajectories or the quantification of riverine litter fluxes by promising videometry systems installed at river mouths. Remote sensing from satellites maybe also helpful to detect the presence and monitor “litter windrows” in the south-east Bay of Biscay.

» Quantify litter inputs from the fisheries sector on a basis of repeated measurements both in the coastal and open waters to better understand the contribution of sea-based versus land-based sources in the Bay of Biscay.

» Overall, coordinate floating litter monitoring based on harmonized sampling protocols and reporting to facilitate data exchange at regional scale, in particular, between France and Spain, but also to feed existing European and global platforms for data management as the European Marine Observation and Data Network (EMODnet) or the Global Partnership on Marine Litter (GMPML).

TARGET 2: MODELLING FLOATING LITTER DISTRIBUTION AND FATE IN THE BAY OF BISCAY AND SOUTH-EAST BAY OF BISCAY

Numerical models can provide extremely useful insights on the behaviour of FML in open and coastal waters of the Bay of Biscay. However, significant challenges remain unresolved, including modelling the accumulation and dispersion patterns of FML at finer-scale (e.g., submesoscale) or measuring the relative importance of the different physical process (e.g., the wind effect or beaching) to accurately predict its final fate. Research is needed to:

» Expand modelling analysis to different floating objects for accurately simulate macrolitter pathways and destiny in the Bay of Biscay. Since windage largely control the transport and beaching in the region, more simulations are recommended to parameterize the windage effect on the diverse object types observed both in open and coastal waters of the Bay of Biscay.

» Enhance the comparison between modelling results and data derived from drifters to assess and improve the reliability of the modelled pathways of floating litter, including model validation for diverse windage parametrizations.

» Explore the importance of physical processes as beaching, stranding, and backwashing that may affect the spatial distribution of FML in the coastal area of the Bay of Biscay. It is important to consider the highly diversified coastline with rocky cliffs and shores, sandy and muddy shores, and estuaries which may affect the accumulation rates.

» Identify the geographical sources of FML in the Bay of Biscay by means of backward simulations considering both the effects of surface currents and windage.

» Extend the range of land- and sea-based sources modelled, including entry points of marine litter not incorporated in previous studies as maritime traffic or recreational fishing and compare, when possible, the simulation results with visual records of floating macrolitter.

» Determine the meso and sub-mesoscale processes behind litter windrows formation by implementing nested modelling with higher resolutions than basin scale at critical areas of litter windrows occurrence (e.g., south-east Bay of Biscay).

» Investigate the 3D representation of FML transport in the Bay of Biscay to better understand the dynamic vertical displacement and fate of litter, including sinking or re-suspension processes of floating items from surface to seafloor.

» Benefit from other biological modelling studies oriented to better understand fish egg transport patterns in the Bay of Biscay due to the similarities on size and shape between microlitter, particularly pellets, and fish eggs.

- Further investigate the importance of climate change in the Bay of Biscay for FML circulation. One example of this might be modelling future scenarios of sea level rising and their corresponding impact on the removal of litter trapped in accumulation areas at the coastline and along the river basins.

TARGET 3: GOVERNACE FOR PREVENT AND MITIGATE FLOATING MARINE LITTER IN THE BAY OF BISCAY AND SOUTH-EAST BAY OF BISCAY

Understanding the abundance, composition, distribution, and fate of FML, including marine habitats of high ecological value most affected (e.g., Marine Protected Areas), is key to implement appropriate prevention and mitigation strategies for the Bay of Biscay. However, given the nature and scale of the problem, the diversity of sources and the inherent mobility of floating marine litter, actions are needed at many levels, at all stages of the life cycle of the objects, and by all stakeholders. It is therefore recommended to:

- Examine the effectiveness of the current international and European instruments transposed at regional scale for marine litter management (e.g., EU's Directive on single-use plastics or Directive on port reception facilities). It is necessary to identify gaps and reasons for any lack of implementation in current French and Spanish strategies and legislation.
- Promote best practices of marine litter on-board Spanish and French fishing fleets and gear marking schemes. It is needed to increase the availability of port reception facilities within the Bay of Biscay for end-of-life gear to prevent and reduce fishing-related items (e.g., abandoned lost or otherwise discarded fishing gear).
- Explore fundings for floating marine litter collection at the Bay of Biscay by fishermen on a voluntary (and paid, or otherwise incentivized) basis and for providing facilities and equipment to storage the litter generated on-board.
- Reinforce the actions for collecting and monitoring floating marine litter which are already underway in the south-east Bay of Biscay (e.g, https://fmltrack.rivagesprotech.fr/) and support the multi-stakeholder mechanisms between France and Spain to tackle marine litter at transboundary level.
- Allocate financial resources to measure the effectiveness of wastewater plants and sewage systems in the south-east Bay of Biscay. Most treatment plants are still unable to filter all types of polluting materials derived from land-based sources, particularly microplastics, so it is essential to reduce the impact of wastewater at regional and sub-regional scale.
- Overall, increase funding for data collection and research to generate evidence required for FML management and policy change proposals at all scales.

9

PRE-DOCTORAL TRAINING ACTIVITIES

Scientific publications

Ruiz, I., Basurko, O. C., Rubio, A., Delpey, M., Granado, I., Declerck, A., Mader, J., and Cózar, A.: Litter Windrows in the South-East Coast of the Bay of Biscay: An Ocean Process Enabling Effective Active Fishing for Litter, Front. Mar. Sci., 7, https://doi.org/10.3389/fmars.2020.00308, 2020a.

Ruiz, I., Burgoa, I., Santos, M., Basurko, O.C., García-Barón, I., Louzao, M., Beldarrain, B., Kukul, D., Valle, C., Uriarte, A., Rubio, A., 2022. First assessment of floating marine litter abundance and distribution in the Bay of Biscay from an integrated ecosystem survey. Marine Pollution Bulletin 174, 113266. https://doi.org/10.1016/j.marpolbul.2021.113266

Ruiz, I., Abascal, A. J., Basurko, O. C., and Rubio, A.: Modelling the distribution of fishing-related floating marine litter within the Bay of Biscay and its marine protected areas, Environ. Pollut., 292, 118216, https://doi.org/https://doi.org/10.1016/j.envpol.2021.118216, 2022.

Ruiz, I., Rubio, A., Abascal, A. J., and Basurko, O. C.: Modelling floating riverine litter in the south-eastern Bay of Biscay: a regional distribution from a seasonal perspective, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-316, 2022.

Basurko, O. C., Ruiz, I., Rubio, A., Beldarrain, B., Kukul, D., Cózar, A., Galli, M., Destang, T., and Larreta, J.: The coastal waters of the south-east Bay of Biscay a dead-end for Neustonic plastics. [Manuscript submitted for publication], 2022.

Andrés, M., Delpey, M., Ruiz, I., Declerck, A., Sarrade, C., Bergeron, P., and Basurko, O. C.: Measuring and comparing solutions for floating marine litter removal: Lessons learned in the south-east coast of the Bay of Biscay from an economic perspective, Mar. Policy, 127, 104450, https://doi.org/https://doi.org/10.1016/j.marpol.2021.104450, 2021.

Training courses attendance

Marine environmental awareness course. ProSea Foundation – Marine Education. 20th – 21st February 2018. Pasaia (Spain).

COSMO-VIEW tool. Training on the implementation of the Lagrangian model COSMO. 18th September 2018. ICM-CSIC. Barcelona (Spain).

“Gestión de residuos en el sector pesquero en el País Vasco”. Confederación Española de Pesca (CEPESCA) en el marco del proyecto “Fish-recycle: Apoyando la transición de la industria pesquera hacia una economía circular”. Online course 15th March – 15th August 2018.

Introducción al análisis objetivo y la asimilación de datos. 23rd – 25th October 2019. Pasaia (Spain).

Conference, seminar and workshop attendance

Uhinak - III Congreso transfronterizo sobre Cambio Climático y Litoral. 6th -7th March 2018. Irún (Spain).

II Jornadas RETOLASTRE- Convenio internacional de aguas de lastre: aplicación y retos. 10th December 2018. Bilbao (Spain).

Clean Atlantic and MyCoast project workshops and Numerical modelling and hackathon workshops. 9 -13 December 2019. Lisboa (Portugal).

Conference seminar and workshop presentation

Ruiz I., Basurko O.C., Rubio A., Ferrer L., Uriarte A., Mader J., Salvo V.S., Azurmendi I. (2018). Life LEMA Project: Facing the challenge of floating marine litter in the Bay of Biscay. XVIth International Symposium on Oceanography of the Bay of Biscay (ISOBAY 16), Anglet (France), 5-7 June 2018. Proceedings, p 58.

Dávila X., Louchart A., Delarbre J., Gauthier V., Ruiz I., Manso I., Artigas L.F., Pascal L., Caballero A., Basurko O.C. (2018). Relation between mesoscale dynamics and phytoplankton/floating marine litter distribution in the South-East Bay of Biscay (POSTER). XVIth International Symposium on Oceanography of the Bay of Biscay (ISOBAY 16), Anglet (France), 5-7 June 2018.

Rubio A., Basurko, O.C., Granado, I., Ruiz, I., Ferrer L., Epelde I., Liria P., Asensio J.L., Mader J., Delpey M., Declerk A., Larronde I. (2018). ICBM-Kolloquium SoSe2018. 4 July 2018. Oldenburg (Germany).

Ferrer L., Basurko O.C., Granado I., Ruiz I., Rubio A., Mader J. (2018). Marine litter and small wooden boats in the Bay of Biscay. VI International Symposium on Marine Sciences (ISMS, EOF, SIQUIMAR, ISC-CDM, REDIBAL, WORKSHOP PATRIMONIO CÍES), 20–22 June 2018, Vigo, Spain. Abstract book (EOF), 31.

Basurko O.C., Beldarrain B., Larreta, J., Kukul D., Rubio A., Granado I., Ruiz I., Cozar A., Galli M. Martin I., Uriarte A., Louzao M., Puillart I., Santos M., Dávila X. (2018). From coastal to oceanic micro-meso and macroplastic in the SE Bay of Biscay. MICRO 2018 Fate and Impact of Microplastics: Knowledge, Actions and Solutions. Lanzarote, Canary Islands, Spain. 19-23 November 2018.

Ferrer L., Basurko O.C., Granado I., Ruiz I., Rubio A., Mader J., Nogues M., Epelde I., Liria P., De Santiago I., Asensio J.L., Caballero A., Del Campo A. (2018). Modelling the drift of marine litter in the Bay of Biscay. 6th International Coordination Meeting of the Coastal and Shelf Seas Task Team (COSS-TT) including a special session of the Marine Ecosystem Analysis and Prediction Task Team (MEAP-TT). Puertos del Estado, Madrid, Spain, 19-21 September 2018.

Ruiz I., Basurko O.C., Epelde I., Liria P., Delpey M., Rubio A., Declerck A., Asensio J.L., Mader J. (2019). Monitoring floating riverine by advanced technology. EGU General Assembly, 7-12 April, Vienna (Austria) .

Ruiz I., Basurko O.C., Rubio A., Granado I., Mader J. (2019). Floating litter on the coastal waters of the south-eastern of the Bay of Biscay: abundance, composition, sources and spatial distribution. EGU General Assembly, 7-12 April, Vienna (Austria) (poster).

Ruiz I., Basurko O.C, Declerck A., Delpey M., Rubio A., Mader J. (2019). MARLICE 2019 - International Forum on Marine Litter and Circular Economy. An operational Life LEMA tool for monitoring and management support of marine litter on near-shore. 1-12 April. Sevilla (Spain).

Ruiz I., Basurko O.C., Epelde I., Liria P., Rubio A., Mader J., Delpey M. (2020). Monitoring floating riverine pollution by advanced technology. EGU General Assembly, 4-8 May, Vienna – online (Austria).

Ruiz I., Basurko O.C., Epelde I., Liria P., Rubio A., Mader J., Declerck A., Delpey M. (2020). Monitoring floating riverine pollution by advance technology. Workshop on Basuras Marinas of ISMS conference “BAMAR 2020”. Barcelona (Spain), 1-3 July 2020

Ruiz I., Abascal A.J., Rubio A., Basurko O.C., Granado I., Mader J. (2020). Assessment of marine litter distribution from fishing sector in the Bay of Biscay. Workshop on Basuras Marinas of ISMS conference “BAMAR 2020”. Barcelona (Spain), 1-3 July 2020

Liria P., Epelde I., de Santiago I., Garnier R., Abalia A. , Ruiz I., Mader J. (2020). KOSTASystem, a costal videometry technology: development and applications. 9th EuroGOOS International Conference: Advances in Operational Oceanography: Expanding Europe’s ocean observing and forecasting capacity. 3 - 5 May. Online edition.

Ruiz I., Epelde I., Liria P., Rubio A., Basurko O.C., Mader J., Delpey M. (2021). Monitoring floating riverine pollution by advanced technology. Workshop: Close range remote sensing of macroplastics. 11 - 12 November. Koblenz – online (Germany).

Biermann L., Kikaki K., Martin C., Ruiz I., van Emmerik T. (2021). EGU General Assembly 2021. Co-convener. Session: Detecting and Monitoring Plastic Pollution in Rivers, Lakes, and Oceans. April 19 – 30 . Vienna – online (Austria).

Delpey M., Declerck A., Basurko O.C., Ruiz I., Rubio A., Epelde I., Mader J. (2022). Observation et modélisation de la dispersion des débris flottants dans la zone côtière du sud-est du Golfe de Gascogne. GDR Polymères & Océans. 27-29 June. Brest (France).

Scientific advisory activities

Plastiko Zero Urdaiabai. Oral presentation “Plastikoak Bizkaio Golkoan”. 8 June 2019. Busturia (Spain). Advisoring activities on microplastic sampling by citizen science.

Fundación Lurgaia. Oral presentation “Recogida y gestión inteligente de basuras marinas para autoridades locales. Proyecto LIFE LEMA”. 29 October 2019. Bilbao (Spain).

Lecturing activities

MS MER, Course - Instrumentation and Measurement in Operational Oceanography. Lecture for “Marine Litter and LIFE LEMA project”. 9th June 2020. Donostia – San Sebastian (Spain). Online edition.

MS MER, Course - Instrumentation and Measurement in Operational Oceanography. Lecture for “Marine Litter and LIFE LEMA project”. 27th April 2021. Donostia – San Sebastian (Spain). Online edition.

RIMER 2019 – Research in Marine Environment and Resource. International Postgraduate Course. Abundance, distribution, sources and risk assessment of floating litter in the south-eastern of the Bay of Biscay. 28th January -February 1st, 2019. Donostia -San Sebastian (Spain).

RIMER 2020 - Research in Marine Environment and Resources. International Postgraduate Course. Distribution, origin and sustainable management of floating marine litter in the SE of the Bay of Biscay.3 - 7 February, 2020. Donostia- San Sebastian (Spain).

Other contributions

Reviewer of scientific papers:

- RIM 2019 (topic monitoring of seabed litter)
- Nature 2022 (topic modelling of marine litter)