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# Numerical Modelling of Plastic Debris Transport and Accumulation throughout Portuguese Coast

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**ABSTRACT**

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Microplastic (MP) accumulation and dispersal is a growing problem at a global marine scale. The accumulation of MPs in aquatic systems is increasing due to their high perseverance and inadequate management, affecting all marine environments and could adversely affect ecosystem services and even human health. The study of these contaminants, namely their concentration and spatial distribution, as well as their physical characteristics, is fundamental, to mitigate and reduce the associated risks. Due to the high population density living on the Portuguese coast, this area is a zone of high contamination by MPs, being the rivers their main transport mode to coastal waters. In order to understand the distributions of MPs and the way they evolve in space and time, is essential to develop studies in this area. Thus, the purpose of this study is to simulate the transport and accumulation of MPs along the Portuguese coast and adjacent waters. The methodology followed comprised the development and implementation of a three-dimensional model using the Delft3D suite, coupling the Flow and particle-tracking (D-WAQ PART) models. Modeling predictions show that all MPs move to north following the local hydrodynamics. The higher density MPs with diameters of 5 mm tend to sink more than those of lower density with 10 mm diameters, which in turn tend to travel longer distances.. The main factors that influence the distribution and accumulation of MPs in the study area are the local hydrodynamic and geomorphology, and the MPs diameter. These results have a large number of applications, including detecting optimal removal locations, reducing the impact on the ecosystem, and understanding the flows of MPs pollution.

**ADDITIONAL INDEX WORDS:** *Modeling, microplastics, tracking, Portuguese coast, Delft3D-Part.*

## INTRODUCTION

Plastics are defined in the literature as synthetic organic polymers, which emerge as a result of the polymerization of monomers extracted from oil or gas (Thompson *et al*., 2009). Regarding polymer type, there are a wide range of polymers annually produced.The buoyancy of particles is a function of their physical properties and largely determines their eventual fate (Zhang, 2017). Plastic density, size and shape are the main properties governing the buoyancy and mobility of microplastics (MPs) (Zhang, 2017).

MPs are the most abundant and potentially harmful fraction of plastic debris in the ocean, constituting 54% of the global mass of anthropogenic waste (Hoellein *et al*., 2014). Under these conditions, marine pollution from MPs has been recognized as a worldwide environmental and ecological threat (GESAMP, 2015).

The environmental impacts of MPs include the provision of substrate for undesirable microorganisms and ingestion hazards to marine organisms due to their size, shape and color (Schuyler *et al*., 2014). MPs also act as dispersal vectors of chemical additives (Rochman, 2015), once organic and metal pollutants are absorbed onto their surface, due to their hydrophobic nature (Antunes *et al*., 2013). The highest concentrations of these contaminants are often detected in estuaries and coastal areas (Wagner and Lambert, 2018). Once released in the environment, these particles can be transported to marine ecosystems by freshwater systems (Eerkes-Medrano, Thompson, and Aldridge, 2015). It has been estimated that the freshwater and terrestrial ecosystems are recognized as a major source and transport pathways of plastics to the ocean (Horton *et al*., 2017).

More than half of the Portuguese population live near the coast, which makes the coastal zone a hotspot for MPs contamination (Cole *et al*., 2011). The Portuguese coast presents complex oceanographic conditions and morphologic features, with several rivers flowing into the Atlantic Ocean. Antunes, Frias, and Sobral (2018) found a strong correlation between annual average river flow and MPs accumulated on beaches in winter/autumn.

Using field data, several studies were carried out to quantify and characterize MPs in Portuguese beaches (Antunes, Frias, and Sobral, 2018; Martins and Sobral, 2011), and coastal waters (Frias, Otero, and Sobral, 2014). Particle-tracking models have been used to simulate the trajectory and distribution modeling of MPs

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in several ports abroad (Lammerts, 2016), North Sea (Stuparu *et al*., 2015), and world ocean (Lebreton, Greer, and Borrero, 2012). However, there are still no studies describing the trajectory and distribution of MPs in Portuguese coastal waters.

In this context, this study aims to give a step forward in the comprehension of the distribution patterns of different types and sizes of MPs incoming from rivers along the Portuguese coast and adjacent waters, using the Delft3D suite, coupling the Flow and particle-tracking (D-WAQ PART) models.

## METHODS

Delft3D-FLOW is a multi-dimensional hydrodynamic (and transport) simulation numerical model which calculates non-steady flow and transport phenomena (Deltares, 2014a). The hydrodynamic conditions calculated in the Delft3D-FLOW modules are used as input for the PART module. The PART module simulates transport and simple water quality processes by means of a particle tracking method using the flow data from the FLOW module (Deltares, 2014b).

### Hydrodynamic and Transport Model

The Delft3D-Flow was used to simulate the hydrodynamic conditions of the domain shown in Figure 1. This was represented by a 249×192 regular grid, with ~1950 m resolution. The bathymetry used results from the interpolation of topohydrographic surveys to the numerical grid. The model used 15 z-layers along the vertical, with more refined surface layers increasing towards the bottom layers, as the particles will be released at the surface near the shore. Even if they tend to sink the focus will be at the first layers due to the low depth in the study zone.

Boundary conditions for hydrodynamics (water level, velocity, water temperature, and salinity) were provided by the hourly results from Portuguese Coast Operational Modelling System (PCOMS) (http://www.maretec.org/). The flow was forced using the Riemann invariant, which is a combination of water level and velocity, and the hydrodynamic forcing was prescribed as time-series per-layer specified. Ocean heat transport model was applied using hourly results from the Weather Research Forecasting (WRF) model (www.wrfmodel.org), provided by the Regional Forecast Agency Meteogalicia (www.meteogalicia.es), with a spatial resolution of 12 km. This model takes into account air temperature, relative humidity and ocean cloudiness to calculate heat losses from convection, evaporation and back radiation, along with forecast of zonal and meridional wind and mean sea level pressure.

As example of the model accuracy, the Multi-Scale Ultra-High Resolution (MUR) sea surface temperature (SST) daily data set (https://coastwatch.pfeg.noaa.gov/), with horizontal resolution of about 1 km, was compared with the predicted data, by interpolating the satellite data grid into the model grid. Difference between predictions and satellite data was calculated, as well as, the root mean square error (RMSE), BIAS and Pearson correlation.

### Particle-Tracking Model

To assess the dynamical spatial distribution of particles in three dimensions by tracking their path in time, Delft3D-WAQ Part module was used. The study was performed using polypropylene (PP) and polyethylene terephthalate (PET) (plastics with the lowest (900 kg m$^{-3}$) and highest densities (1370 kg m$^{-3}$)) with different sizes (10 μm and 5 mm diameters) of the most produced types of plastics.

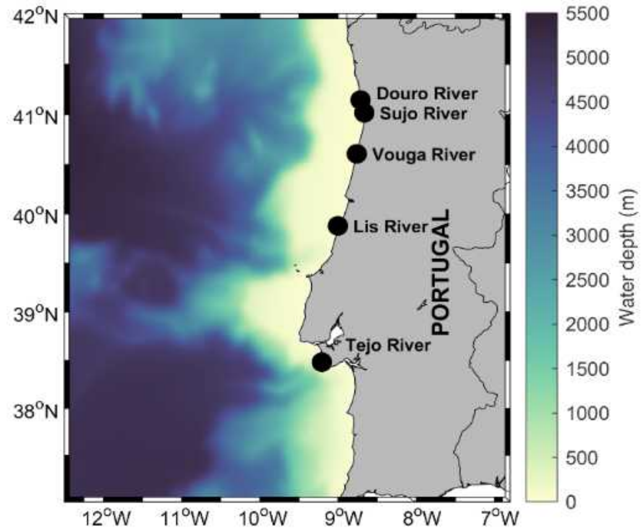


Figure 1. Bathymetry of the Portuguese coast and location of the particles release points (black dots).

Assuming that the majority of the marine litter enters the area of interest via rivers constantly, the release of the particles was set only at the rivers mouth that are characterized by hourly continuous discharges. Since no data about the influx rates in the case study environment is available at the time of this research, the selection of rivers (Douro, Sujo, Vouga, Lis and Tejo, Figure 1) and the percentages of releases have been calculated based on data obtained by Antunes, Frias, and Sobral (2018). Winter season was simulated since the river flows are higher during that period.

Overestimated values have been chosen for the discharge characteristics, following a procedure analog to Lammerts (2016), namely the discharge rate (1 m$^3$/s) and the concentration (100 kg m$^{-3}$). The number of discharged particles (405 000) was chosen as a balance between the number of particles used by Lammerts (2016) and Stuparu *et al.* (2015) in their study areas, considering the relation between the dimensions of their case studies and the present study area. The particles are released at the surface layer, and their position can be influenced by advection (transport by water flow), diffusion/dispersion (random component) and settling (density difference between the particle and the ambient water). The settling velocity ($V_s$) of each particle at a given time was calculated with the Stokes' law (Lamb, 1994), which means that the plastic particle is a sphere and that the settling depends on the density difference between the particle and the ambient water, the particle's diameter and the viscosity of the water.

Total concentration of particles along the water column was computed, in order to visualize and quantify the particles vertical distribution. An evaluation of the differences between the trajectories of different types of plastic with different sizes was also performed. The trajectory and predominant deposition areas of the particles were also analyzed, *i.e.* whether they were off or on the continental shelf and whether they were on the surface, middle or bottom layers. The continental shelf was defined as ~ 60 km from the shoreline and the remainder was defined as offshore. The percentages of particles in each area were also calculated.

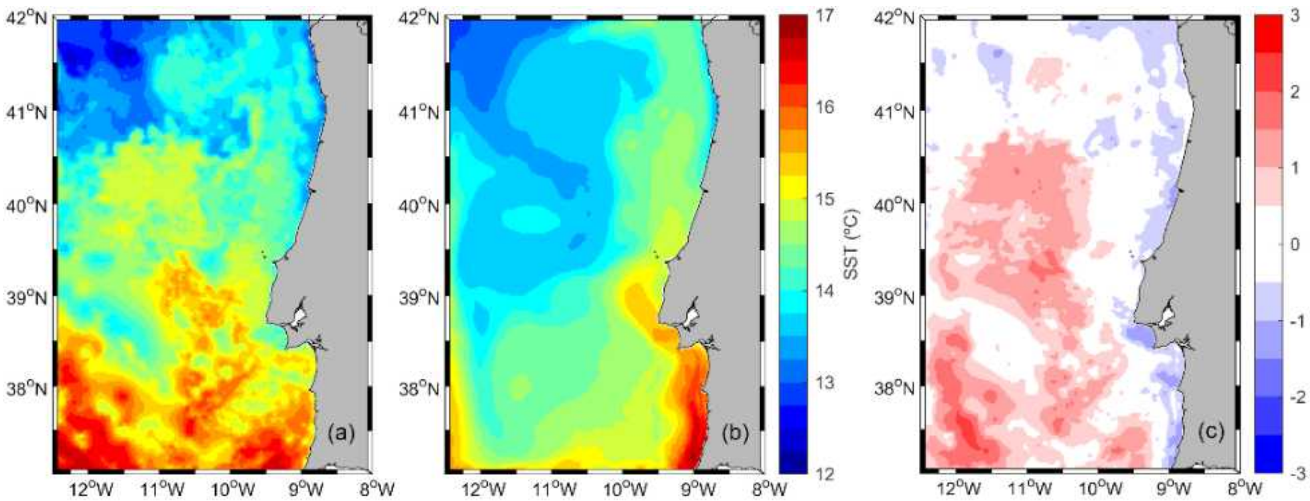


Figure 2. SST (ºC) on February 6, 2010 of satellite (a), model predictions (b) and difference between measured and predicted SST (c).

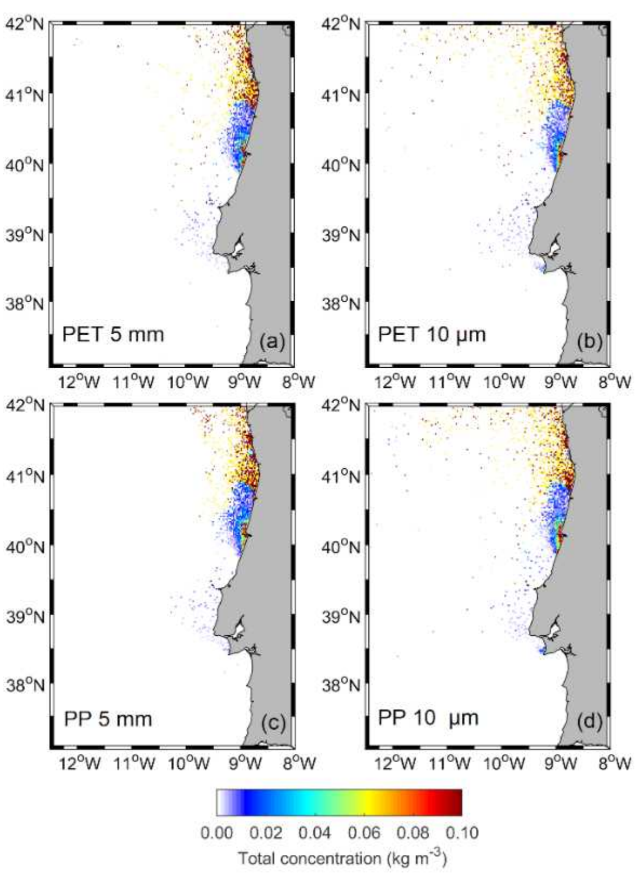


Figure 3. Total concentration (kg m$^{-3}$) of particles in the water column, calculated in last day of simulation (February 28, 2010): (a) PET with 5 mm; (b) PET with 10 µm; (c) PP with 5 mm; (d) PP with 10 µm.

## RESULTS

Figure 2 shows SST patterns obtained from satellite (a), model predictions (b) and difference between both (c) on February 6, 2010, and is provided to demonstrate the high model skill in reproducing the local hydrodinamics and transport features. Comparing Figures 2a and 2b, is observed similar predicted and observed SST patterns (meridional gradient of temperature, characterized by lower temperatures at the north, increasing southward), as well as lower water temperatures near coast than offshore. The highest difference between the predicted and satellite SST (Figure 2c) was found in the south offshore zone (about 2ºC).

Statistical parameters were also determined to assess the model skill. The BIAS value (-0.08ºC) suggests that predictions tend to underestimate the satellite SST. Difference between predicted and satellite average SST are about 0.4 ºC. The RMSE between the predicted and observed SST is 0.74°C, and a correlation coefficient of 0.64 was found, indicating that the data are highly correlated.

Figure 3 shows the total concentration of the different types and diameters of MPs. There is a general tendency for particles to accumulate near the coast, mainly in the northern zone. This result was expected, taking into account that particles were released near the coast and considering the dominant northward currents resulting from the south winds, characteristic of winter in the studied region.

Regarding the plastic size, a similar dispersion pattern was observed, independently of plastic type. On the other hand, when comparing MPs with same density, a highest dispersion was observed on particles with lowest dimension.

In order to analyze the accumulation areas of the particles incoming of each river, total concentration along the water column was also computed for PET with 10 µm (Figure 4), since it shows a higher dispersion (Figure 3b). It can be observed that all MPs tend to move north, following the hydrodynamic of the region. The largest input to the ocean results from the Lis river discharge (Figure 4d), followed by Douro (Figure 4a), Tejo (Figure 4e), Vouga (Figure 4c) and Sujo (Figure 4b) rivers. MPs accumulation was observed in areas close to the coast, northward of the release point, with the exception of Tejo river.

Table 1 shows the horizontal and vertical percentage of MPs (including the deposited MPs), considering different types and diameters. Comparing the different types of plastics with the

Table 1. *Percentage (%) of MPs, considering different types and diameters on the surface (S) (0-20 m), middle (M) (20-150 m) and the bottom (B) layers (> 150 m) on platform, and off-platform on the surface (S) (> 0-20 m), middle (M) (20-4000 m) and bottom (B) layers (> 4000 m).*

| MP Characteristics | | | Platform | | | | Off | | | | General | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | D | $V_S$ (m/s) | S | M | B | Total | S | M | B | Total | S | M | B |
| PP | 5 mm | -1.4 | 80.1 | 9.2 | 10.7 | 52.8 | 2.2 | 97.6 | 0.2 | 47.2 | 43.3 | 51.0 | 5.7 |
| | 10 µm | $-5.6\times10^{-6}$ | 82.7 | 12.3 | 5.0 | 56.7 | 5.4 | 94.5 | 0.1 | 43.3 | 49.2 | 47.9 | 2.8 |
| PET | 5 mm | 3.9 | 80.0 | 9.1 | 10.9 | 52.3 | 2.3 | 97.1 | 0.6 | 47.7 | 42.9 | 51.1 | 6.0 |
| | 10 µm | $1.6\times10^{-5}$ | 81.5 | 13.1 | 5.5 | 55.0 | 5.0 | 94.9 | 0.1 | 45.0 | 47.1 | 49.9 | 3.0 |

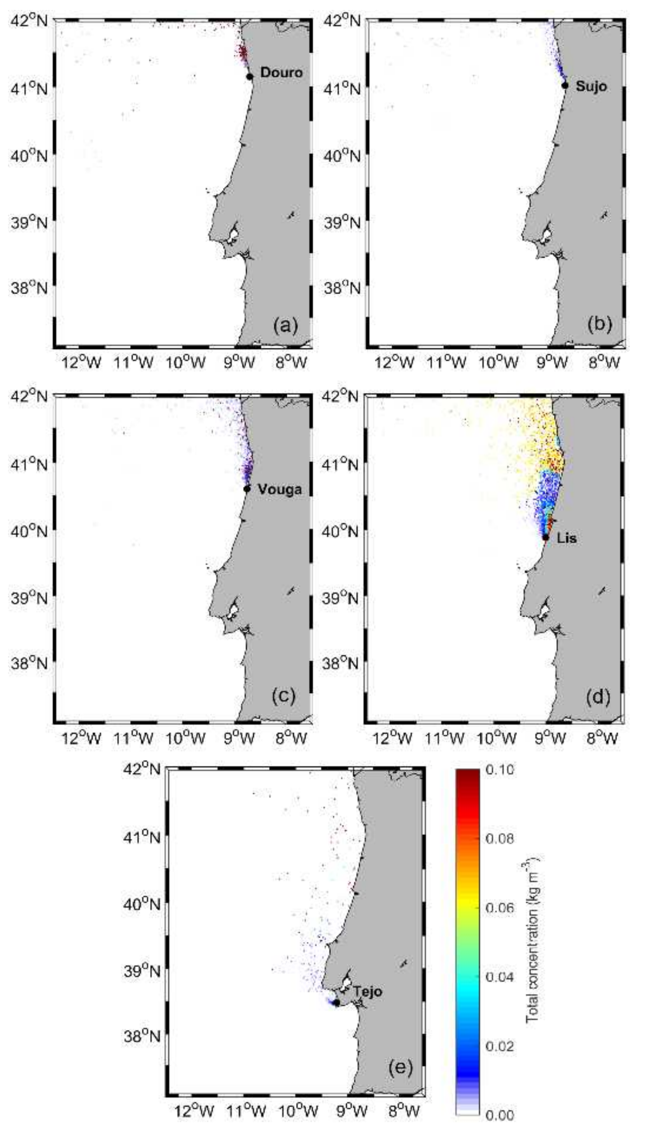


Figure 4. Total concentration (kg m$^{-3}$) of PET particles (10 µm) in the water column, calculated in last day of simulation (February 28, 2010) per river: (a) Douro; (b) Sujo; (c) Vouga; (d) Lis; (e) Tejo.

same diameter, those with higher density than water ($V_s$ >0) have lower percentages on the surface. For example, the 5 mm PP have 43.30% of particles in the surface layer, whereas 5 mm PET have 42.90%. Higher density particles have higher percentages in the bottom layer than lower density plastics.

Analyzing PP and PET with different diameters, MPs with smaller diameter tend to remain more on the surface (42.9% PP and 47.08% PET) than those with larger diameter (43.30% PP and 42 42.95% PET. The 5 mm diameter particles tend to sink and remain in the middle layer (50.99% PP and 51.00% PET) or bottom layer (5.7% PP and 5.9% PET) and may even deposit on the seabed. The total percentage of particles on and off the platform leads to the conclusion that the smaller diameter particles disperse less, showing 56.67% and 55.00% (10 µm PP and 10 µm PET, respectively). On the other hand, particles with higher density than water have lower percentages on the platform than those with lower density than water.

On the platform, the highest percentages were found on the surface, regardless of size and type of plastic, as expected considering that particles are continuously released on the surface. The lowest percentages found vary according to the characteristics of the plastic, *i.e.*, lower percentages in the middle layer of particles of 5 mm; lowest percentages of particles in the surface are of PET, considering their higher density and tendency to sink; and lower percentages in the bottom in 10 µm particles, since PP have lower density and tends to float. The highest concentrations offshore were found in the middle layer, while the lowest in the bottom, probably due to increased local depth. The particles with highest percentage at surface were the PP with 10 µm, since they have lower density.

## DISCUSSION

The analysis of the statistical parameters determined to assess the model performance reveals an accurate reproduction of the hydrodynamic behavior of the study area. It should be in mind that the simulated SST corresponds to the bulk temperature (average water temperature of surface layer). In this study, model surface layer thickness is 1.87 m. Therefore, skin SST can be significantly different from the bulk SST, especially under weak winds and high incoming sunlight (Fairall *et al*., 1996; Wick *et al*., 1996). The RMSE value obtained is very similar to the obtained by Mateus *et al.* (2012) in a previous numerical modelling work reproducing local Summer conditions.

There is a general tendency for particles to accumulate in the northern area (Figure 3), according to the results obtained by Lebreton, Greer, and Borrero (2012), that using a global ocean circulation model coupled with a Lagrangian particle tracking model, found floating debris accumulation in northern Portugal.

From the results obtained it was found that the MPs released form each river (Figure 4) move to the north, accumulating near the coast in the area near the discharge site, with the highest MPs release resulting from the Lis river (Figure 4d). These results are in agreement with those of Martins *et al*. (2011), who collected MP samples from 5 beaches along the Portuguese west coast, and found the smallest amount of MPs in the southernmost beaches and the largest amount in the nearest beach to the river Lis, followed by the beaches near the Tagus river, indicating that the results obtained are consistent with field data.

Considering the vertical accumulation distribution (Table 1), there are smaller percentages of the PET particles on the surface than PP particles, as found in Stuparu *et al.* (2015). They found that the concentration of PET and PS (polysterene) (higher density than seawater) have lower concentrations at the surface, since they settle quite fast towards the bottom. On the other hand, they found that PE (polythylene) particles (lower density than seawater density, such as PP) remain in the surface layer. In addition, Stuparu *et al.* (2015) showed that 5 mm diameter PE particles follow water flow and spreads out more than 10 µm diameter plastics, in line with Zhang *et al.* (2017), which verified that large plastic debris with density lower than seawater floats at high velocity over rather long distances transported by surface current and wind. However, the results showed that the larger floating particles (PP 5mm) travel shorter distances than the 10 µm particles, even though there are in larger quantities off the platform. Although the results obtained are not consistent with the results of the studies cited above, it cannot be concluded that they are in total disagreement since the extensive spatial variation of the particles may be related to the hydrography and geomorphological factors of the region, as mentioned by Galgani, Souplet, and Cadiou (1996), thus explaining the shortest distance traveled by the larger diameter particles. These particles (5 mm) travel shorter distances and have higher percentages at the bottom of the platform than the 10 µm particles, in agreement with findings by Antunes, Frias, and Sobral (2018) and Martins *et al*. (2011) in this study area, which sampled sediments from the west Portuguese coast and mostly obtained MPs with diameters of 4 and 5 mm.

## CONCLUSIONS

The results obtained showed that the dispersion of different type of MPs with the same dimension is identical. The largest differences were found comparing MPs of different diameters, with greater dispersion of smaller MPs. The tendency of all MPs is to head north, due to the prevailing south winds, inducing northward currents along the Portuguese coast. MPs tend to be on the surface when they are on the platform, and to spread along the water column when they are offshore. In the bottom layer, there are higher percentages of higher density and size particles, and in the surface layer are found lower density and size particles.

In summary, MPs distribution along the Portuguese coast is strongly dependent on the rivers discharge intensity and location and the main influence on their fate is the local hydrodynamics and geomorphology, as well as the size of the MPs. This study contributes to improve the understanding about the fate and transport of MPs along the Portuguese coast and to detect critical accumulation zones.

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## LITERATURE CITED

Antunes, J.C.; Frias, J.; Micaelo, A.C., and Sobral, P., 2013. Resin pellets from beaches of the Portuguese coast and adsorbed persistent organic pollutants. *Estuarine, Coast and Shelf Science*, 130, 62–69.

Antunes, J.; Frias, J., and Sobral, P., 2018. Microplastics on the Portuguese coast. *Marine Pollution Bulletin*, 131, 294-302.

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

Deltares, 2018a. Delft3D-Flow User Manual Version 3.15. Delft, The Netherlands, pp. 672.

Deltares, 2018b. Delft3D-Waq PART User Manual Version 2.15. Delft, The Netherlands, pp. 130.

Eerkes-Medrano, D.; Thompson, R.C., and Aldridge, D.C., 2015. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritization of research needs. *Water Research*, 75, 63–82.

Fairall, C.W.; Bradley, E.F.; Godfrey, J.S.; Wick, G.A., and Edson, J.B., 1996. Cool-skin and warm-layer effects on sea surface temperature. *Journal of Geophysical Research: Oceans*, 101, 1295-1308.

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

Galgani, F.; Souplet, A., and Cadiou, Y., 1996. Accumulation of debris on the deep sea floor off the French Mediterranean coast. *Marine Ecology Progress Series*, 142(1/3), 225-234.

GESAMP, 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment. (Kershaw, P.J., ed.). *Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection*. Rep. Stud. GESAMP No. 90, 96 p.

Hoellein, T.; Rojas, M.; Pink, A.; Gasior, J., and Kelly, J., 2014. Anthropogenic litter in urban freshwater ecosystems: distribution and microbial interactions. *PLoS One*, 9(6), e98485.

Horton, A.A.; Walton, A.; Spurgeon, D.J.; Lahive, E., and Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science Total Environment*, 586, 127–141.

Lamb, H., 1994. *Hydrodynamics* (6th Edition*)*. Cambridge University Press. ISBN 978-0-521-45868-9, pp 706.

Lammerts, M.W., 2016. Marine litter in port areas – developing a propagation model. Master's Thesis. Delft University of Technology, pp. 43.

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

Martins, J. and Sobral, P., 2011. Plastic marine debris on the Portuguese coastline: A matter of size? *Marine Pollution Bulletin*, 62, 2649-2653.

Mateus, M.; Riflet, G.; Chambel, P.; Fernandes, L.; Fernandes, R.; Juliano, M.; Campuzano, F.; de Pablo, H., and Neves, R., 2012. An operational model for the West Iberian coast: products and services. *Ocean Science*, 8, 713–732.

Rochman, C.M., 2015. The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. *In:* Bergmann, M., Gutow, L., Klages, M.

(Eds.), *Marine Anthropogenic Litter*, vol. 4. Springer, Berlin, pp. 117–140.

Schuyler, Q.; Hardesty, B.D.; Wilcox, C., and Townsend, K., 2014. Global analysis of anthropogenic debris ingestion by sea turtles. *Conservation Bioloy*, 28(1), 129–139.

Stuparu, D.; van Der Meulen, M.; Kleissen, F.; Vethaak, D., and El Serafy, G., 2015. Developing a transport model for plastic distribution in the North Sea. *In: E-proceedings of the 36th IAHR World Congress* (28 June–3 July, 2015, The Hague, the Netherlands).

Thompson, R.C.; Swan, S.H.; Moore, C.J., and Vom Saal, F.S., 2009. Our plastic age. *Philosophical Transactions of Royal Society B Biological Sciences*, 364, 1973–1976.

Wagner, M. and Lambert, S., 2018. Freshwater Microplastics – Emerging Environmental Contaminants? The Handbook of Environmental Chemistry, *Springer Open*, 58, 303.

Wick, G.A.; Emery, W.J.; Kantha, L.H., and Schluessel, P.,1996. The behavior of the bulk-skin sea surface temperature difference under varying wind speed and heat flux. *Journal of Physical Oceanography*, 26, 1969-1988.

Zhang, H., 2017. Transport of microplastics in coastal seas. *Estuarine, Coast and Shelf Science*, 199, 74–8.