Interreg
France (Channel Manche) England
European Regional Development Fund
EUROPEAN UNION

PREVENTING PLASTIC POLLUTION

An application of a macroplastic fate and transport model to real catchment data

The Rivers Trust

Contents

1 Introduction

Plastic that enters the environment does not remain in situ and can be transport by forces such as wind and surface runoff. Here I present an adaptation of the Plastic Pathfinder model (Mellink et al., 2022) that incorporates geographical data on factors that may determine macroplastic transport and fate.

1.1 Methods

1.1.1 Study sites

The adapted Plastic Pathfinder macroplastic transport and fate model was parameterised for two catchments, one in England and one in France (Figure 1).

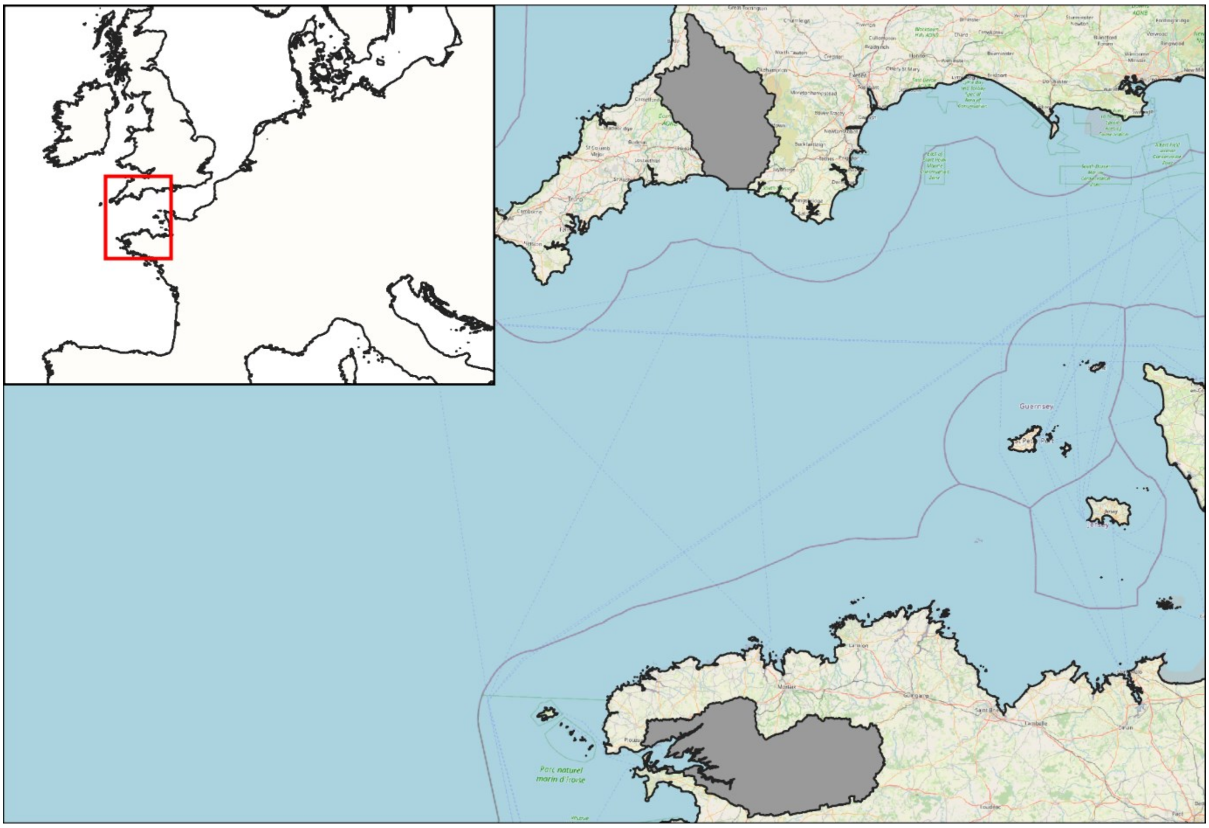


Figure. Tamar and surrounding coastal catchments and catchments draining into the Bay of Brest.

2 Model concept

The Plastic Pathfinder operates on principal criterion from the field of sedimentology, which states that sediment motion is initiated when driving forces overcome resistive forces. The two driving forces in the model are wind and surface runoff and the resisting force, i.e. the terrain friction, is a result of the combination of land use and terrain slope, which is translated to a wind and a surface runoff threshold. For each geographic location in the river basin, wind speed and surface runoff flux are compared with their respective thresholds. Macroplastics are only mobilised when thresholds are surpassed. If only the wind threshold is surpassed, macroplastics move in the direction of the wind at that location. In cases when only the surface runoff threshold is surpassed, macroplastics will move in the direction of the surface runoff, which is equal to the direction of the steepest downhill terrain slope at that location. Finally, if both thresholds are surpassed, the model randomly picks either the wind or the surface runoff direction at that location along which the macroplastics will move. In our implementation of Plastic Pathfinder we used the default thresholds for wind and surface runoff for each land use and slope (Mellink et al., 2021). Surface runoff thresholds were derived from global absolute runoff trends found in the Global Runoff Reconstruction model (Ghiggi et al 2019). At the end of each iteration (day) the model records where each cluster of macroplastic is. The four possible fates for macroplastic in this model are:

- Leaked directly from land to sea.
- Leaked directly from land to river.
- Leaked directly from land to adjacent land outside the model domain (catchment).
- Macroplastic remains on land within model domain.

The Plastic Pathfinder only models the transport and accumulation of plastics in terrestrial environments. When the wind or surface runoff forces MPW cluster(s) from a land into a river grid cell, the simulation of its transport ends and the plastics will remain (and fictively accumulate) in that river grid cell. The Plastic Pathfinder can be coupled to hydrological models to simulate the transport (and retention) of plastics in freshwater environments as well. For further details of on the Plastic Pathfinder see Mellink *et al.* (2021).

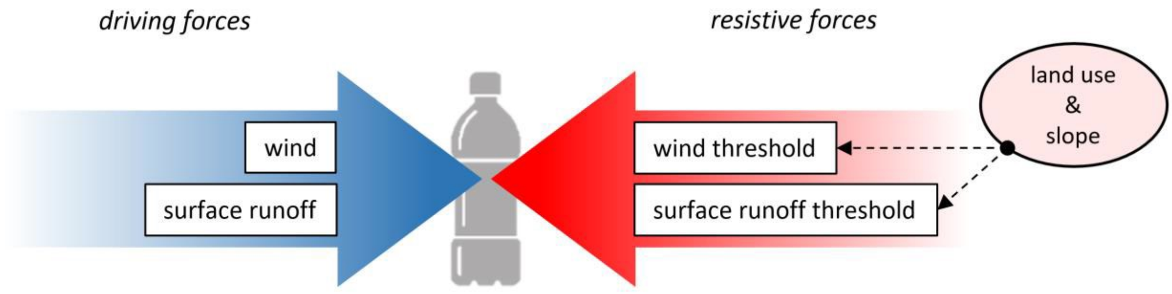


Figure. 1. Schematic representation of the main model concept of the Plastic Pathfinder. Plastics are mobilized once the driving forces exceed the resistive forces (Mellink et al., 2022).

2.1.1 Inputs

Our implementation of Plastic Pathfinder used globally available geographical spatial data, making it transferable to any catchment (Table 1). All data sources are common to the UK and Europe with equivalent datasets available for the globe. The spatial distribution of mismanaged plastic waste is generated from population density and broad regional waste generation and mismanagement values for northwest Europe (Lebreton and Andrady, 2019) such that mismanaged plastic waste (MPW) for each cell is equal to:

$$A_{yearly}(x) = PP \times MSW_{capita} \times Y(x)$$

$$MPW_{yearly}(x) = MWF \times A_{yearly(x)}$$

$$MPW(x) = \frac{MPW_{yearly}(x)}{365}$$

where x is one day, Y is the number of people per cell, MSW_{capita} is the annual municipal solid waste produced per capita annual and PP is the fraction of that waste that is plastic. Only a fraction of plastic waste (A_{yearly}) is mismanaged, this is the mismanaged waste fraction (*MWF*). This fraction is divided by 365 to obtain a value for daily mismanaged plastic waste (*MPW*) (Figure 2).

Table 1. Input data used to drive macroplastic transport and fate model.

Input	Source
Land use	Corine Land Cover (EEA, 2012)
Elevation	EU-DEM (Copernicus Land Monitoring Service, 2016)
Wind speed	MIDAS Open: UK hourly weather observation data (Metoffice 2020) and Météo France
Wind direction	MIDAS Open: UK hourly weather observation data (Metoffice 2020) and Météo France
Rainfall volume	MIDAS Open: UK hourly weather observation data (Metoffice 2020) and Météo France
Population	Global Human Settlement Population Grid (European Commission, 2015)
Municipal Solid Waste production	Lebreton and Andrady, 2019
Mismanaged Waste Fraction	Lebreton and Andrady, 2019
Plastic fraction	Lebreton and Andrady, 2019

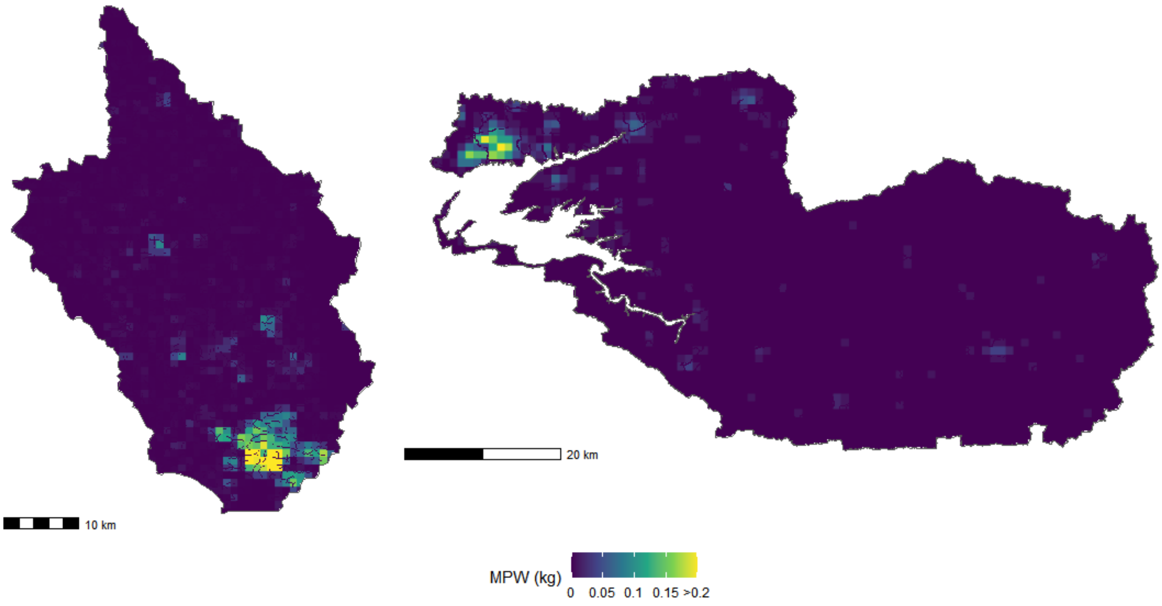


Figure 2. Daily mismanaged plastic waste (MPW) inputs to the Tamar (A) and Bay of Brest (B) river basins.

Land use data from Corine Land Cover (EEA, 2012) was used to drive macroplastic transport and fate model aggregated to the six land use classes used by Plastic Pathfinder (Table 2). Slope and aspect (degrees) were derived from a digital terrain model using the *terra* package (Hijmans, 2022). All geospatial data were resampled to a resolution of 100 m. All data pre-processing was conducted in *R 4.1* (R Core Team, 2021) through the *stars 0.5* (Pebesma, 2021) and *tidyverse 1.3* (Wickham et al., 2019) packages. All pre-processing (R) and Plastic Pathfinder scripts are available at https://github.com/The-Rivers-Trust/ppp.

Table 2. Corine land cover classes matched to Plastic Pathfinder land use classes.

Basin		**Cumulative MPW leaked directly from land to sea**	**Cumulative MPW leaked directly from land to river**	**Cumulative MPW leaked directly from land to adjacent land outside model domain**	**Total remaining**	
					on land	in basin
Tamar	MPW (kg)	31340.7	169932.4	7851.7	241962.8	405862.2
	Percent of total generated in basin	7.0%	38.2%	1.8%	54.4%	91.2%
Bay of Brest	MPW (kg)	1665.6	103775.9	3831.3	123088.9	214716.1
	Percent of total generated in basin	0.8%	47.1%	1.7%	55.9%	97.5%

3 Results

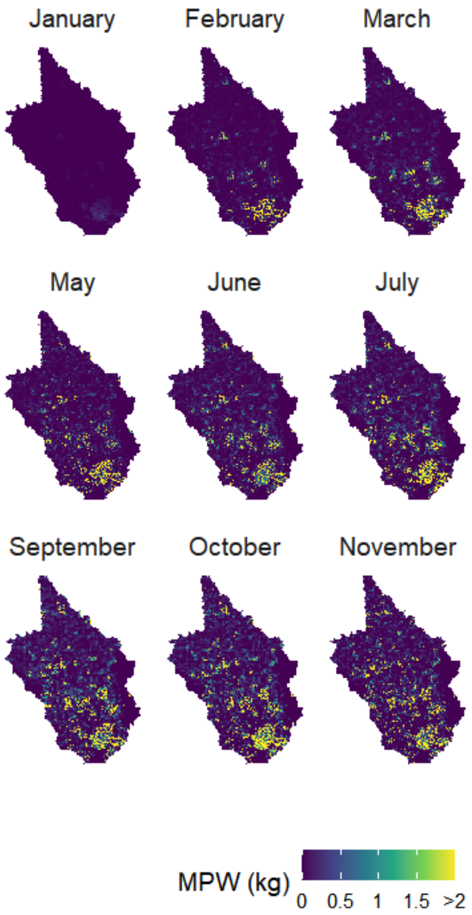
Summarises of MPW fate after 365 days are shown in Table 2.

- Rivers were the greatest sink for MPW leaving the land in both basin.
- The majority (>50%) of MPW generated on land over 365 days remained on land.
- More than 90% of MPW remains within the basin it is generated in.

Table 3. Emissions of mismanaged plastic waste (MPW) from the Tamar and Bay of Brest river basins.

Plastic Pathfinder land use classes	Corine Land Cover class
Urban land	Artificial surface (all level 1)
Bare land	Open spaces with little or no vegetation (level 2)
Grass/shrub land	Wetlands (level 1), pastures (level 2), and shrub and/or herbaceous vegetation associations (level 2)
Agricultural land	Arable land (level 2); permanent crops (level 2), and heterogeneous agricultural areas (level 2)
Forest	Forest (level 2)
Water	Freshwater (level 2)

Figures 3 and 4 show the distribution of MPW through time for the model application in each basin, illustrating that the majority of MPW does not travel far beyond the cell in which it is generated. In both cases it is possible to see that MPW density peaks in the urban centres of Plymouth and Brest in August and



October and July and October, respectively. **Figure 3**. Mismanaged plastic waste (MPW) distribution in the Tamar river basin on the 1st day of each month.

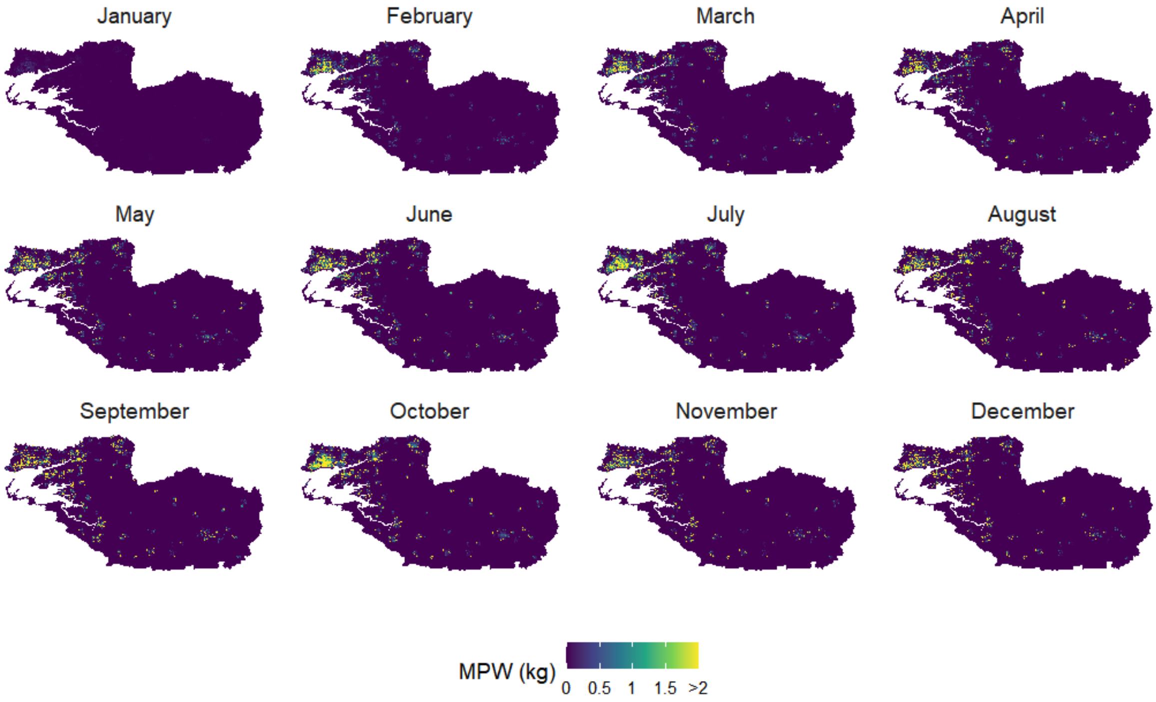


Figure 4. Mismanaged plastic waste (MPW) distribution in the Bay of Brest river basin on the 1st of each month.

Figure 5 A and B show the cumulative fluxes of MPW through time for the model application in each basin, illustrating that the majority of the MPW produced on land, which is leaves land, reaches the river. This type of output provides valuable insights in the fate of MPW generated on land. Additionally, the distribution of MPW over the terrestrial and freshwater compartments of the river basin can be plotted through time (Figure 5 C and D). This graph shows that after ~300 – 325 days, the MPW stock on land may stabilise which implies that the MPW produced on land approximately equals the amount of MPW lost. Please note that no removal processes in the river system were included in the model (e.g., beaching or transport to the ocean).

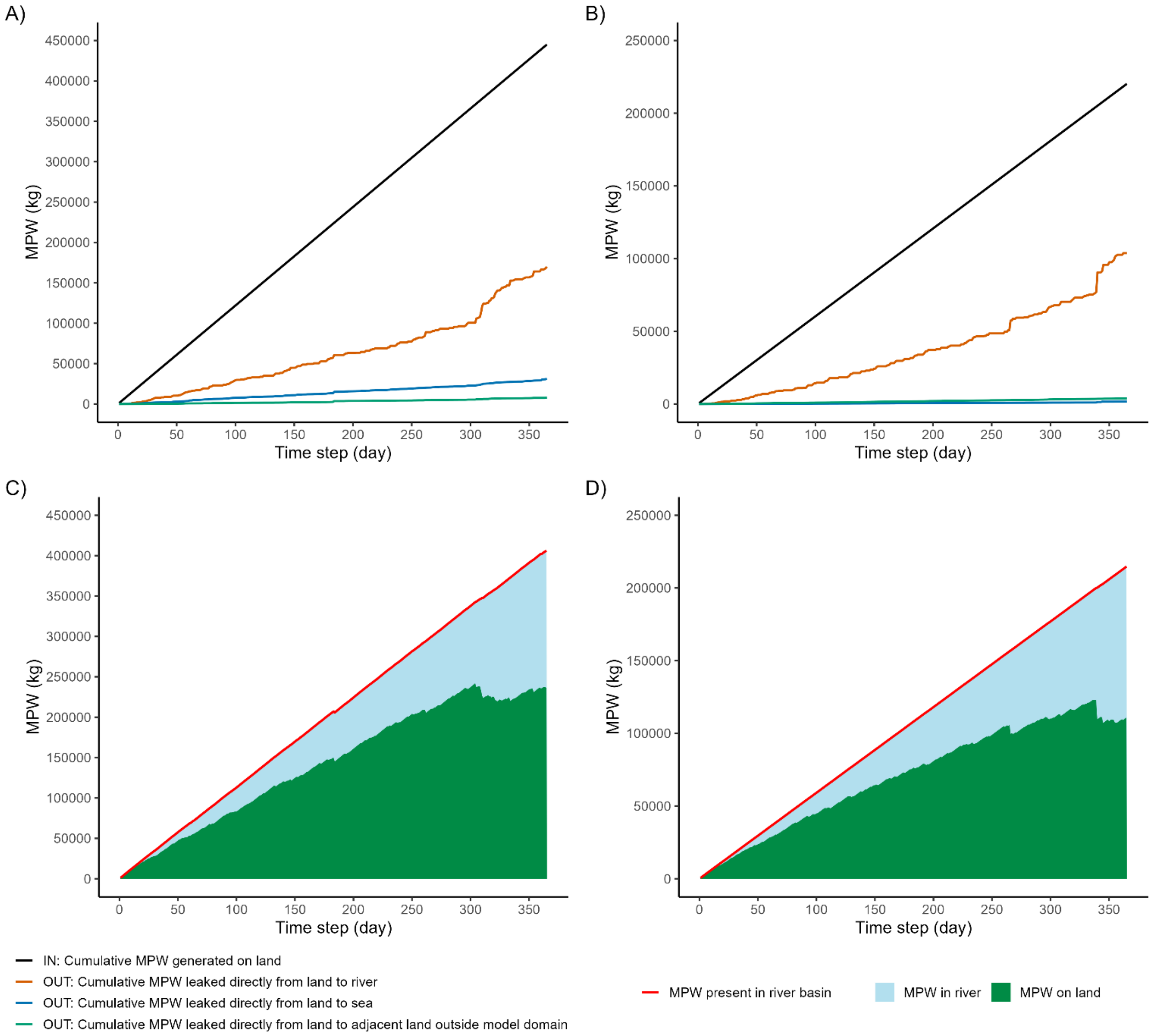


Figure 5 (A, B) Cumulative output fluxes of mismanaged plastic waste (kg) of the terrestrial compartment of the Tamar (A) and Bay of Brest (B) river basin modelled in the model application. (C, D) The total amount of MPW (kg) present in the entire Tamar (C) and Bay of Brest (D) river basin, i.e., on land and in the river.

3.1 Conclusions and improvements

I have presented the adaptation of the Plastic Pathfinder model to use geographical inputs of population, land use and topography to better understand the transport and fate of macroplastic waste at the river basin scale. Following this step forward it is important that some additional functionality is built into the model:

- Possibly the most important element and area of uncertainty in the Plastic Pathfinder is the values used for the resistance of each land use type and slope to MPW transport by wind and surface run off. As a preliminary step we propose a sensitivity analysis of these thresholds to determine their importance in the model outputs.
- Meteorological data used to transport the mismanaged plastic waste in this model application is derived from a single point near the mouth of each river basin. Future iterations of the model could use distributed meteorological data to make the effects of wind and surface run off more representative for each grid cell.
- Municipal solid waste (MSW) generation is assumed constant spatially, between rural and urban populations, and temporally. Parameterisation of waste generation between rural and urban populations could be achieved through comparison of MSW data from predominantly rural and urban local authorities. These data would also provide an insight into the temporal variation of MSW generation.
- The fate of MPW leaked to the river could be modelled by coupling the Plastic Pathfinder with a river plastic transport model, for example with the model developed by Newbould et al. (2021).
- Patterns illustrated by the MPW distribution maps may be useful for targeting litter picking surveys, however these outputs should only be used when more detailed information, cited above, is available.

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