AN APPROACH TO PARAMETRISATION OF COASTAL SOURCES OF MICROPLASTICS PARTICLES IN NUMERICAL MODELS

Andrei Bagaev, Atlantic branch of Institute of Oceanology, Russia
Irina Chubarenko, Atlantic branch of Institute of Oceanology, Russia

a.bagaev1984@gmail.com

An overview of modern approaches to the problem of parametrisation of sources of marine waters microplastics pollution from the coastline is conducted. The estimates of Europe's plastic production along with mismanaged plastic waste percentage that might be the source of microplastics particles input to marine environment are presented. A semi-empirical formulation for the particles source intensity is suggested. It considers the main factors of local anthropogenic pressure for the coastal spot location for the given coordinates. Both advantages and disadvantages of such an approach along with possible ways for improvement are discussed.

Keywords: microplastics, numerical modelling, the Baltic Sea, anthropogenic pollution

I. INTRODUCTION.

Numerical simulation of environmental processes is always a challenging problem: with all our knowledge we are certainly unable to embrace all the forcing, processes and events in both natural environment and human activity. Thus, the necessity of parametrisation of many of them arises, and every parametrisation is supposed to express the influence of some *key factor* but in *the most simple* (i.e. – practically convenient) way. This balance of importance versus model simplicity is always problem-specific and highly dependent on the goal of the simulation, that leads to the development of plenty of model approaches, particular parametrisations, input/output parameters, etc.

In modelling of microplastic pollution of seas and oceans, the most complicated question for today is how to describe coastal sources of microplastic particles. While sources of plastic macro-litter can be associated with cities, popular beaches, or ports, the generation of microplastic particles involves many physically complicated environmental processes like UV-degradation, mechanical destruction in swash zone, settling and re-distribution by currents, re-suspension/re-deposition by storm waves, etc. Which of these processes must be taken into account and how to parametrise them – is a hot question, still practically not discussed in literature.

According to existing naming conventions, the microplastic is the particles of synthetic polymers with different complex shapes and typical size ranges from 1 to 5 mm [1]. Such range is, first of all, determined by the methods of collection and identification of the particles, i.e. neustonic net mesh size, and optical microscopes resolution [2]. Despite emerging interest to that interdisciplinary problem, it is hard to tell that terminology in that area of knowledge is well established and widely accepted.

Very often microplastic appears toxic itself, but what is more dangerous, since it has large effective surface, it adsorbs different ecotoxicants, e.g. poly-chlorinated byphenils [2, 3]. If microplastics gets into a digestive system of marine micro-organisms, it may cause an effect of "false fullness" and propagate up through a food chain, that in turn leads to accumulation of toxic chemicals in the bodies of marine mammals and birds [4]. The researchers found that microplastics might serve as a transport mechanisms for invasive species from different ecosystems [5]. Nowadays microplastics pollution is found even in the Antarctic ice fields [6].

The aim of the present paper is to summarize our knowledge on the sources of microplastics in the marine environment and to propose a new way for parametrisation of the particles input in the model of microplastics transport for the Baltic Sea.

II. NET PLASTICS BALANCE ESTIMATE

Let us concentrate first on the net balance of plastic waste net flow in a semi-enclosed see, like the Baltic Sea, for example. It is widely accepted that 80% of it come from land sources and the rest 20% -- from the sea-based sources. The latter are typically placed along the intense shipping routes and are easily localized in space, but are hard to yield to quantitative assessment. The land-based sources are localized at the river estuaries, major cities, and beaches. All of those places are in contact with two principal natural actors: hydrodynamics and geomorphology which makes distribution of plastic waste at sea very patchy [7]. The human factor makes waste input irregular in time.

For the last decade plastics production and demand in Europe has been showing very slow growth, henceforth the speed of waste dumping into surrounding seas might overcome the growth rate. That might be the reason why plastic pellets became background contamination for the samples taken across the Mediterranean beaches (e.g. Malta, [8]). On the other hand, many Baltic countries implemented “zero dump” laws that prohibit dumping plastic waste to the land-fills, which, in turn, might decrease waste input rate. It seems reasonable to assume that plastic waste concentration will remain more or less stable in the Baltic environment for the next decades, despite its much lower abundance.

According to [9], Table 1 shows a volume of “mismanaged plastic waste” (i.e. plastics waste that escaped recycling) for the Baltic countries estimates at 28 000 kg per day.

Table 1. Mismanaged plastic waste input for Baltic countries (from [9])

Country	Coastal population	Inadequately managed plastic waste [kg/day]	Mismanaged plastic waste [kg/person/year]
Denmark	5 376 386	0.0*	0.37
Estonia	878 021	13295.703	6.94
Finland	2 927 674	0.0*	1.83
Germany	8 837 035	0.00014	3.54
Latvia	1 432 078	24650.935	7.19
Lithuania	443 894	8363.564	7.85
Norway	4 131 679	0.0*	2.19
Poland	3 272 933	36715.231	4.75
Russia	10 812 537	197225.826	7.30
Sweden	6 202 234	0.0*	0.37

*According to official data on production and waste management. Collateral plastic litter input is underestimated.

Fig 1. schematically represents the relation between actual waste input and generation of microplastics pollution with a focus on the unknown links of chain.

Let us now try to estimate a net balance of the microplastics pollution in the Baltic Sea. It is important to take into account the demand of plastics in Europe: which consists of 50% heavy and 50% light [10] plastics. Light particles (with a positive buoyancy) will float away with the surface currents and after a certain time will be removed from the surface waters. Denser particles along with the less dense ones affected by biofouling should sink in a few days and deposit in bottom sediments.

Firstly, the surface currents that mainly outflow to the North Sea seem to be the main factor of the negative balance of microplastics with densities less than brackish water of the Baltic Proper. Actual rate of the removal might be estimated if we improve our knowledge on the mean concentrations of microplastics, but unification of measurement methods [11] is very important.

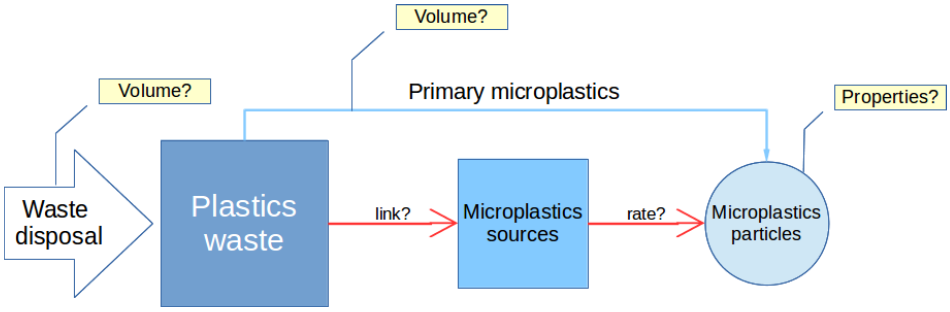

Fig 1. A pathway from unprocessed plastic waste to the microplastics pollution in marine environment.

Secondly, the denser plastics should be accumulated and deposited at the bottom (mainly in the shallow area close to the coast, with a high chance to be re-suspended), but also – in the deep-water area, which might be considered as another way of microplastics removal [5]. To estimate the rate of deposition for different types of plastics, we need to know their settling velocities. Study [12] discovered surprisingly low levels of microplastics at the sea surface when compared to those in the bottom sediments of the deep sea.

These two reasons provide relatively low concentrations of floating microplastics particles in the surface waters of the Baltic Sea [7, 13]. According to different scenarios of numerical modelling in [14] and [15], the Baltic Sea accumulates relatively low levels of plastic waste (much less than Mediterranean or Pacific); possibly, this is due to the currents regime that supports renewal of surface waters. Study [7] reports similar orders (10 particles per litre) of counts of microplastics for the opposite parts of the Baltic Sea, with a slight increase at the German coast. Authors of [12] give mean microplastics densities in the Mediterranean of 400 particles per litre.

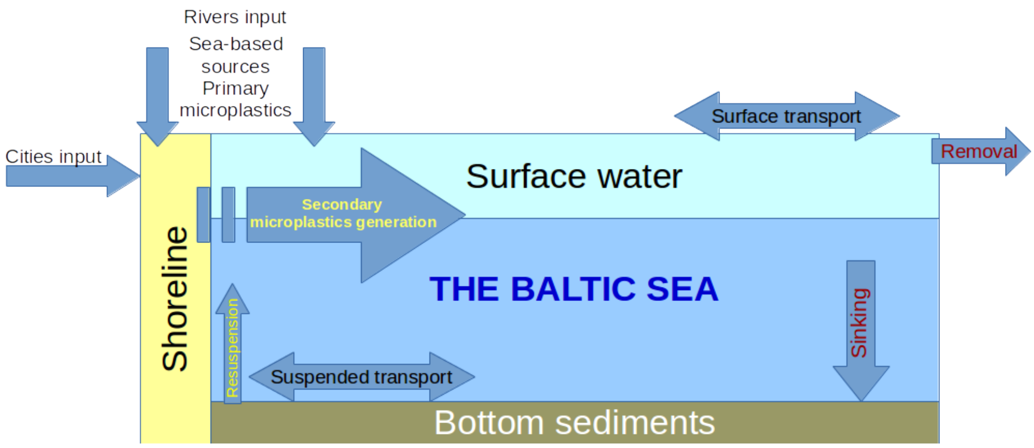

Fig. 2. Conceptual representation of a net plastics balance in the Baltic Sea marine environment.

Common practice is to distinguish “primary” microplastics, e.g. industrial pellets, textile fibres, and microbeads from cosmetics, from the “secondary” microplastics that results from a partitioning of large plastic waste, fishing nets, etc. The latter processes manifest themselves most actively in the coastal zones. Unlike with the macroplastics [16], it is very hard to establish the origins of the microplastics samples, since the macro-waste degradation requires very long exposure to oxygen-rich environment and UV-radiation. The direct input of primary microplastic from the sea-based sources and the land-based sewage facilities might be assumed as much lower than input generated by the breaking pieces of plastic waste and storms removing microplastics from the beaches. Many authors, like [17], support the idea of microplastics particles accumulation at the shoreline, but its rate remains unknown. K-L. Law in [18] hypothesized the processes of microplastics removal from the marine ecosystem, but mentioned that rates remain unknown.

The scheme of the described processes is presented in Fig. 2.

From all that has been said it follows that if we were able to describe the generation of microplastics in the shallow-water bottom sediments, then we would able to parametrise the input of microplastics in the model. In such a case, first thing we need to take into account is the type of the bottom sediments.

When estimating the net input of the microplastics into the marine ecosystem along with surrounding beaches and estuaries, one needs to keep in mind that the only available data on the anthropogenic footprints for now are the statistical information on the average amount of mismanaged plastic waste (see Table 1). Importance of such numbers is contracted by the fact of long exposure of the existing huge plastic deposits to the allocating and equalizing action of the currents and winds. For example, there is no significant distinction in microplastic pollution levels between Slovenian beaches with different extent of human use [19].

III. PRESENT APPROACHES TO THE PROBLEM

Methods of numerical modelling of plastic waste transport are pretty well developed for the Global Ocean [14, 20, 21, 22] and data collected during marine expeditions are summarized in [11, 21]. Meanwhile, there is a huge gap between global and regional scale modelling of microplastics, although there is some progress in [5, 23, 24]. Physical properties of microplastics particles are little-known [25, 26], which interdicts their parameterisation in the numerical models for marine environment.

Table 2. A review of papers on the marine plastic waste transportation

Publication	**Loss of particles**	**Transition from coast to the sea**	**Vertical velocity (loss due to sinking)**	**Sources**
[23]	Sedimentation depends on density and Feret’s diameter	Resuspension due to critical erosion velocity	Yes	4 point sources
[27]	Landing, settling, degradation	Resuspension	Yes	5 point sources
[28]	No beaching	N/A	No	Shipping lanes and cities
[14]	A particle is considered ‘beached’ when it is adjacent to a coastal cell. No removal	is not possible	No	Rivers, shipping lanes and cities. Even releases.
[29]	Removing the particles after 10 days of stagnation at the boundary cell	is not possible	No	Rivers, shipping lanes and cities
[24]	Beaching count, no removal	free	No	Day by day release at each grid cell
[20]	Removing the particles after 5 days of stagnation at the boundary cell	is not possible	No	Instant release at each grid cell
[21]	No beaching	N/A	No	Coastal urban population within 200 km zone; large rivers with urbanised estuaries

Dense plastic transport in suspended state is estimated in [3]. Chances to be re-suspended certainly increase with increase in current velocity and significant wave height. Re-suspension was empirically parametrised in the model [27] as 0.2-0.4 particle per day. Laboratory experiments by [23] showed the critical tension values of 0.14 N per m^2 (which corresponds to velocity of 0.2 cm per sec) for HD plastics (1055 kg per m^3 with settling velocity of 28 mm per sec and size ~2 mm), while re-deposition started at 0.087 N per m^2.

Submesoscale effects remain unknown, but for the particles with buoyancy close to neutral it is proven that subsurface concentration is influenced by turbulence. Settling velocity is high enough to settle in 1-2 days, but turbulence makes this time high enough for some heavy re-suspended particles of plastics and amber to be washed ashore after severe storms.

III. RESULTS: SUGGESTED PARAMETERISATIONS

Coastal related input and stranding processes are crucial for assessing budgets of marine litter. We assume that particles of different sizes enter the sea with equal probability, despite the fact that in-situ measurements do not always confirm such distribution pattern [17, 30]. For spheroids with effective diameter of 1-5 mm, there is a linear dependence between the size and the number of particles generated from a large object of a fixed volume [30]. If a particle fits into one of five size classes from 1 to 5 mm with 1 mm step, then overall final quantity of such particles might be linked to the stock of large plastic waste. Polymer fibres should be treated as a separate class. For now it seems reasonable to introduce two major density classes: “heavy” and “light” particles, which could be modelled separately at the initial stage.Table 3 lists the factors affecting the final parameterisation:

- Seasonality manifests itself in plastics waste input as much as in the intensity of grinding action of the sea and natural factors in the coastal zone.
- Distinguishing of the exploited (urbanized, recreational or industrial) coastal zones from those less used reflects the direct anthropogenic pressure. One can assume the cell of a numerical grid as 'exploited' if there is at least one city with a population more than 100 000 people. Presence of objects that increase local level of plastics pollution, such as water treatment plants, ports, industries related to use of polymer pellets, etc. Study [2] demonstrated sufficient increase in the microplastics particle concentration near the water treatment plants at the coasts of the United Kingdom. Putting locations of such objects on the model grid is a very time-consuming task.
- Population density directly influences the quantity of primary microplastics generated by people, e.g. during visiting the beaches, and the volume of synthetic fibres and microbeads (from cosmetics) dumped into the sewer. Study [7] showed that even waste-water treatment plants could not be a guaranteed barrier to stop microplastics from domestic discharge entering the marine environment. The data on the population density are available according to census bureau [31].
- The data on the yearly input of the plastics waste (see Table 1) are needed to define the most influenced coastal zones. As it was mentioned before, 'heavy' plastics will be deposited close to the place of macroplastics destruction.
- Intensity of the wind waves is an additional factor that influences re-suspension and plastics breakdown. It may compensate for low velocities in the near-shore zone for the very tentative approach in the coarse resolved numerical models based on the reanalysis data. Such data are available, for example, via HELCOM [32].
- Type of bottom sediments, last but not the least, has never been taken before into consideration for the mechanisms of microplastics generation. Different efficiency of mechanical destruction of macroplastics into the microplastics in the coastal zone is determined by the different types of bottom sediments. The parameter of 'mechanical conversion' for the different types of sediments (sand, granules, stones, pebble) acting to macroplastics samples is now studied experimentally by our team members. We plan to adapt such information for the numerical model along with available maps of sediments content for the Baltic Sea.

Table 3. Parameters list suggested for parameterisation.

#	Parameter	Units	Possible values	Notes	Variable	Reference
1	Season	-	0.5 ÷ 1.0	Waste input is maximal in Summer	S_Y	[5]
2	Anthropogenic pressure	-	0/1	Waste treatment plant, sewer, port or a large river	A_P	[2], [7]
3	Population	persons	-	Alongshore area × population density	P	[17]
4	Typical plastic waste input for the country	kg/person/year	-	Baltic countries	W	[9]
5	Wind waves	m	-	Climatic value for Significant wave height	S_{WH}	-
6	Shore type	items/kg	clay, sand, pebble, stones	Influences the microplastics generation from macro waste	T_C	-

A combination of the parameters proposed above allows us to parameterise the distribution of intensity of impulse inflow of the microplastics particles for every 'coastal' cell of the numerical grid. Such distribution in turn permits us to include the non-uniform input of the particles in the Lagrangian model of the microplastics transport. The results of the numerical experiments should be then normalized by the direct measurements of the background concentrations of microplastics pollution in the marine waters and in coastal sediments.

The concentration of particles produced in the coastal cell of the grid will depend on the share of the concentration of deposited plastics waste in the yearly input. Upper estimate is $S = \frac{P_i \cdot W_i}{\sum_i P_i \cdot W_i} \in [0..1]$ (here i stands for each of nine Baltic countries). Such concentration is high enough for the calculated nondimensional term S to change insignificantly on account of the waste transport during the period of numerical experiment.

Since the macroplastics decomposition appears non-uniformly, the intensity of the process I should depend on the type of the local bottom sediments T_C , intensity of wind waves action S_{WH}, and the season S_Y; hence, $I \propto S \cdot T_C \cdot S_{WH} \cdot S_Y$. Proportionality coefficients will be defined during our future laboratory experiments.

Specific sources of anthropogenic pressure might also affect the intensity of macroplastics particles input into the coastal grid cell. Such influence may be taken into account with the following parameterisation: $\delta I \propto A_P \cdot S_Y$.

Henceforth, for each grid cell that may act as a generator of microplastics, i.e. where the input of particles in the Lagrangian model must be defined, we will have the value of a scalar non-dimensional function of the source intensity varying from 0 to 1. That allows us to set the impulse input of the particles for the planned calculation of their transport and accumulation in the model proportional to the maximal allowed number of the particles supported by the model and dependent on the reasonable machine time.

IV. Discussion and conclusions

Unlike the existing approaches (see Table 2), we suggested defining and parameterising the input of the primary and secondary microplastics pollution to the marine environment for the subsequent study of its paths of migration and/or deposition. All previous studies transposed the properties of macroplastics to the microparticles and parameterised the source functions from the requirements of the Lagrangian models or from the available data on the plastics waste input. We assume the key factor in that process to be the destruction of plastic objects in the coastal and wave-breaking zones under the influence of photochemical and mechanical agents.

In our study we pointed out the principal agents that define the balance of the microplastics pollution in the Baltic Sea, according to the known in-situ data and circulation patterns of the Baltic Sea. Further on, we listed the parameters that need to be taken into consideration for parameterisation of the microplastics pollution sources. Those factors are relatively easy to define for each grid cell, depending on the available data bases and geological maps. We hope that further laboratory tests will reveal some coefficients of proportionality [33].

As any other semi-empirical approach, our method might be the subject to critics and improvement. Subsequent tests of its efficiency will be done during the numerical experiments.

IV. Acknowledgment

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