European Commission

JRC CONFERENCE AND WORKSHOP REPORT

Report of the 5th meeting of the Network of Experts for ReDeveloping Models of the European Marine Environment

Approaches, methods and tools to assess plastic pollution in the ocean and its impact on food webs

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2023

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JRC133204

PDF ISBN 978-92-68-02634-2 doi:10.2760/114580 KJ-03-23-118-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report:
Duteil, O., Macias Moy, D., Piroddi, C., Serpetti, N., Stips, A., Ferreira Cordeiro, N., Garcia Gorriz, E., Miladinova-Marinova, S., Parn, O., Polimene, L., Booth, S., Compa Ferrer, M., Dabrowski, T., Fuortibuonni, T., Gonzales-Fernandes, D., Laurent, C., Liubartseva, S., Suaria, G., Tekman, M., Tsiaras, K. and Walters, W., *Report of the 5th meeting of the Network of Experts for ReDeveloping Models of the European Marine Environment*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/114580, JRC133204.

Contents

Abstract

The fifth workshop of the 'Network of Experts for ReDeveloping Models of the European Marine Environment' was held on 28-29 November 2022 in Ispra, Italy, jointly organized by DG Environment and DG JRC (Water and Marine Resources Unit) within the framework of the Administrative Agreement "Model development and operation in the context of the Marine Strategy Framework Directive implementation cycle (BLUE2-2020-2023)". The aim of this workshop was to discuss with the wider scientific community the methodologies, tools, datasets and approaches more appropriate to: (i) simulate the quantity, distribution and accumulation of plastic litter in the ocean (both micro and macro plastics) and (ii) assess the potential impact of incorporation and transference of micro-plastics in the marine food webs. The workshop was organized over two days, each dedicated to one of the topics. Presentations by the attendants were followed by extensive discussions on each of the following questions/issues: (i) what elements should be included in Lagrangian models to correctly simulate the behaviour of plastic litter at sea?, (ii) How can we estimate the inputs of plastics into the marine environment?, (iii) What datasets exist about plastic pollution, and how to harmonize monitoring and model data? and (iv) How to best align estimates of plastic debris distribution with marine ecosystems models? This report compiles the discussions held and presents proposal encompassing best practices on how to tackle the issue of '*plastic modelling at sea*'.

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1 Introduction

For the last decade, the EU Commission, and in particular its science Directorate General, the Joint Research Centre (JRC), has been working on building robust and reliable 'earth system models' that incorporate all the elements necessary to simulate the different compartments that influence the dynamics of marine ecosystems (Fig. 1). These models (the 'Blue2 Modelling Framework', Blue2MF) have been used to test the impacts of diverse management options on the status and services of marine ecosystems at different EU basins (e.g., Macias et al., 2019; Piroddi et al., 2021).

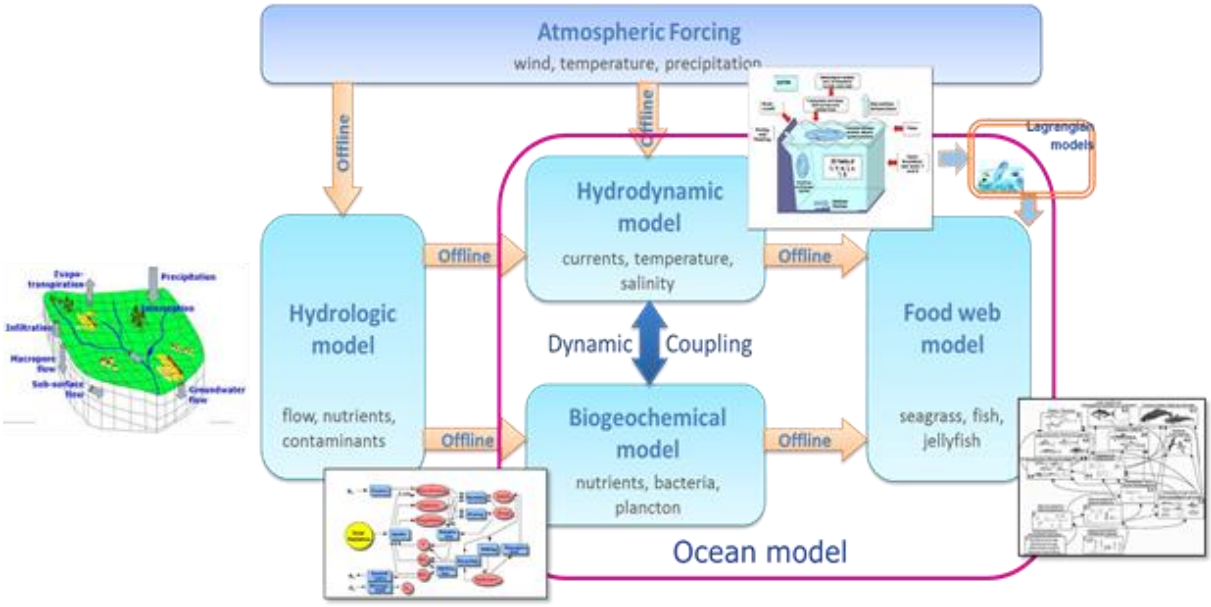

Figure 1: Blue2 Modelling Framework

Plastic pollution of the oceans is a very high priority topic in the context of different EU legislations such as the Marine Strategy Framework Directive (MSFD, descriptor 10), the Zero Pollution Ambition or the Single Use Plastic Directive. However, knowledge about the concentration of plastic debris in our seas and oceans, their transportation and accumulation patterns and of their adverse effects on marine ecosystems and the services they provide is still scarce. As a consequence, recent additions to the Blue2MF have included specific modules to simulate the presence, dispersion, and accumulation of plastic debris in the ocean (e.g., Macias et al., 2019; 2021; Miladinova et al., 2020a and 2020b) and their interaction with the biota (Serpetti et al., 2022 JRC130033).

As previously done for other components of the Blue2MF (Macias et al, 2016; 2017; 2018 and 2020), JRC has engaged with the wider scientific community to discuss the best way to use numerical modelling tools to explore the complex issue of plastic pollution at sea. For this purpose, a 2-day workshop involving a network of modelling experts (MEME) was organized at JRC in Ispra (Italy) on 28th and 29th November of 2022. The workshop was attended by 19 international experts of which 12 present in person and 7 remotely connected. The overarching goals of the workshop were to strengthen the collaboration and awareness within the network of experts and to provide a review of the current understanding of the pollution caused by micro and macro-plastics in the marine and coastal EU ecosystems.

The first day of this workshop focused on the processes impacting marine litter distribution and their resulting ocean dispersion (section 2), the quantification of plastic input into the ocean (section 3) and existing knowledge gaps (section 3). The second day was instead dedicated to food webs and higher trophic levels (section 5). The relevance of the modelling of plastic debris distribution for policy support is discussed in section 6. Discussions have been held throughout the workshops and summarised in section 7. The workshop summary is presented in section 8.

2 Session 1 (day 1): Processes and particles dispersion

This session comprises of 5 presentations, focusing on the capability of Lagrangian models to forecast the dispersion of micro or macro-plastics.

- Effects of Eulerian current, stokes drift and wind while replicating the trajectories of surface drifters (Ove Parn, JRC)

The Lagrangian OceanParcels module was calibrated, and surface trajectories were assessed by a comparison with nine drifters trajectories in the Baltic Sea. Surface drift trajectories are a combination of numerous processes that are challenging to simulate. The final distance between 3 drifter buoys deployed at the same initial location reaches 10 km after 1 week and >100 km after 1 month. In spite of the uncertainty of sub-grid processes, the OceanParcels can replicate the trajectory of drifters. The error was measured every 2 days between the observed drifter buoy and the modelled one, and it was between 1.2–7.8 km when 21 sections were analysed (Parn et al., 2023). The results depended on the parameterisation of Stokes drift and windage. The connection between the Stokes drift and the motions of drifters is strong, especially when wave heights >0.9 m. Stokes drift and Eulerian currents are dominant over windage for wave heights >0.7 m. The role of eulerian currents is most important near the coasts. The study highlights the importance of using a correct parameterisation of windage and Stokes drift.

Discussion: The drifters are located at surface level. Would these results apply to foreign materials/objects

- Modelling marine litter dispersion with the Lagrangian particles tracking model LTRANS_zlev (Celia Laurent, OGS)

LTRANS_Zlev is an offline 3D Lagrangian particle tracking module. It is compatible with Eulerian hydrodynamic fields whose vertical discretisation is based either on the levels of z (depth) or sigma (following the terrain). The model includes several particle behaviours that can be parameterised: neutral, floating, sinking, bottom following, and larval type. Experiments can be performed backwards and forward in time tracking particles advected by three-dimensional currents and wind drift. Horizontal and vertical diffusion effects are as well included. LTRANS_Zlev can be coupled to oil weathering processes (OILTRANS). It is parallelised (Open-MP), permitting a fast execution. A new version of LTRANS_Zlev was developed in collaboration with the JRC in the specific case of the simulation of marine litter in the Black Sea. For this case study, a new behaviour was implemented defining a time-dependent vertical velocity. This velocity changes in time when plastic degrades and different groups of particles are considered, allowing to use different vertical velocities to represent litter of different sizes. Forcing by Stokes drift provided by an external provider was implemented. A new "washing off" process was added, implying that stranded particles return to the sea based on a probabilistic function.

Discussion: A question is how to take into account the role of turbulent kinetic energy and, more generally, the diffusion in the upper water column. This tool can deal with a large number of particles.

- Modelling trajectories of marine litter in Irish waters – the cleanAtlantic project experience (Tomasz Dabrowski, Marine Institute)

This work has been performed as part of the Clean Atlantic project (lead CETMAR, Spain), which aims to increase knowledge, improve capabilities to monitor, prevent and remove (macro) marine litter and raise awareness. (INTERREG Atlantic Area 2014 – 2020, 3.3 MEuros). 18 organisations from 5 EU countries (Ireland, United Kingdom, France, Spain, , Portugal) are involved. The project has been extended to June 2023.

The Irish Marine Institute focuses on the western part of the North Atlantic region. Modelling tools include a large ROMS (Regional Ocean Modelling System) domain (1.1-2.4 km resolution) and 3 high resolution nested zoom regions (70 – 200 m resolution) along the coasts of Ireland. In complement, a wave model based on SWAN (200 m resolution) is used. The model Ichtyop has been used to perform Lagrangian simulations. Ichtyop include windage effect. The windage has been assessed in-situ using different types of drifters (submerged, wind exposed). These data are used to parametrize ichtyop. Furthermore, the particle behaviour can be changed in Ichtyop (buoyant or sinking). Three types of litters are considered (strongly floating, slowly sinking, fast sinking). Another option could be to use another model called OpenDrift, which could be tuned more precisely. Simulations permit to identify natural litter retention and convergence zone. Simulations of dispersion originating from hypothetical sources (either land based: river, port or ocean: fishing grounds) have been performed and „accumulation "hotspots" identified. A limitation of these experiments is the absence of litter resuspension as the sinking litter fall relatively quickly to the seabed and is not subject to resuspension.

Another tool employed is the MOHID Lagrangian tool, a comprehensive library for the MOHID Water system, developed by Maretec (Portugal). This tool considers windage / beaching / effect of waves / floating litter. Experiments with variable and constant river emission have been performed.

The output from the Marine Institute is to deliver maps of floating litter distribution. The litter distribution is averaged for ICES regions for each season. Combined results from all partners include distribution in ICES regions, MSFD MRUs, OSPAR. This work is in progress.

Amongst the developments to the model code considered as part of the future work, subject to funding, are: the resuspension of litter from the bottom, and the implementation of litter buoyancy change with time (this change would be either constant with time or phytoplankton dependent).

Discussion: There is a need to define consistent conditions for particles at the boundaries (seasonality, hydrodynamics) or simply „lose" particles. As a remark, this project focuses only on macroplastics.

- Modelling the pathways and accumulation patterns of micro and macroplastics in the Mediterranean (Kostas Tsiaras, HCMR)

The work has been performed in the context of the EU project CLAIM focusing on the Mediterranean Sea. Lagrangian studies are performed with particles originating from major plastics land-based sources (coastal cities, rivers) to determine micro and macroplastics distribution (model validation using in-situ data, accumulation patterns). A further question is whether an overlap with ecosystem services (MPA, Aquaculture) is present.

The model framework is constituted by high resolution (5km) coupled atmosphere / ocean / wave components. Observational data are assimilated. The Lagrangian model includes a large range of processes: advection / mixing / stokes drift / windage / buoyancy / beaching / biofouling. 6 size classes of microplastics (from 50 um to 2000 um) and 5 classes of macroplastics (5mm to > 20cm). The biofilm (biofouling) is dependent on particle size and bacteria abundance, both of which impact sinking velocityand is particularly important for small particles. Sources of litters are rivers (Lebreton et al., 2017), waste (UNEP 2011), and cities (function of population).

Results show that the abundance of microplastics decreases quickly at surface due to biofouling (fast sinking speed). Most of the total plastic at surface is macroplastics. The effect of waves is important as it causes beaching of the particles. A reasonable agreement exists between modelled and in-situ data for both micro and macroplastics. Sensitivity experiments have been performed to different processes on macroplastics: wind and waves have a strong effect, biofouling is, in comparison, not very important. The surface micro and macroplastic concentration display important differences. High microplastic levels are located close to sources. They are less abundant in open sea due to biofouling induced sinking. Macroplastics are conversely advected offshore by currents, where high concentration patches are found.

Beaching maps have been overlapped with MPAs and Natura 2000 areas. The model framework can be used to quantify transboundary pollution. 4 zooms (800 m resolution) have been implemented (Gulf of Lions, Gabes, Ligurian, Saronikos) in the basin configuration.

Major issues are the large uncertainty of plastic sources (including temporal variability, e.g seasonality) and the limited in-situ data for model validation. In term of processes, beaching needs to be better parametrized as well as fragmentation as it constitutes a link between macro and microplastic, which has a large impact especially for longer time periods.

Discussion: Tides may have a large impact in some regions (e.g Gulf of Gabes). The bacterial biomass is given by the ERSEM model. Data on waste waters is from a UNEP report (2011) and depends on population size.

3 Session 2 (day 1) - Plastics inputs estimates

This session comprises five presentations, focusing on the estimate of plastic inputs into the ocean.

- Reducing uncertainty in riverine plastic inputs to EU seas (Daniel González-Fernández, University of Cádiz)

The work is based on the RIMMEL project (Riverine and Marine Floating Macrolitter Monitoring and Modelling of Environmental Loading – DG JRC – Georg Hanke). Observations are performed close to the river mouth to estimate the litter flux input to the marine environment (González-Fernández et al., 2021). The mean and median are calculated, which permit to extrapolate an annual load. Small rivers are more efficient in transferring floating litter to the ocean than the large ones. It is possible to derive an EU map of floating macrolitter load. Most (70 %) of the floating litter reaches the marine environment through small coastal basins. An important issue is intermittent rivers and flash flood events as large quantities of accumulated plastics can be emitted to the marine environment in a short period of time (a few hours).

The methodology, i.e. how to compute plastic transport by rivers is associated with large uncertainties. It involves many steps: sampling (microplastic) or observations (macroplastic) permit to determine a concentration (items / volume or mass / volume) or a flux (items / hour). A yearly mass flux is obtained based on mass estimates. Finally, regression models are used to obtain a global estimate. These regression models are however not well constrained. As a consequence, these global estimates vary by one or two orders of magnitude. The number of rivers to be considered in the modelled outputs is not clear and varies between the studies. These uncertainties hamper the implementation and monitoring of measures (Zero Pollution Targets 2023): the expected reductions by interventions would simply operate within the uncertainty range of the current models. Uncertainties may be up to 4 orders of magnitude for some European rivers when existing models are compared.

Regarding macroplastics, the conversion from the number of items results in 2-3 order magnitudes of uncertainty. Furthermore, the transport mechanisms and temporal flux dynamics are not well constrained, e.g., in case of extreme events, which are often not considered in annual estimates. A threshold effect may occur in the case of floods: the macroplastic is transported only if the flood reaches a certain threshold (van Emmerik et al., 2022).

Reducing uncertainty in riverine plastic input of the ocean requires an improvement of the observation system: harmonized monitoring methods, more reliable mass estimates and sustainable long-term observations to understand variability and transport mechanisms. Currently, neither the predictor (theoretical estimates of mismanaged waste) nor the output variables (litter concentration or fluxes) of the models are well characterized by the available empirical data. (www.marinelitterlab.eu)

- Lagrangian tracking plastics in the Mediterranean Sea: CMCC's experience and perspectives (Svitlana Liubartseva, CMCC)

The Fondazione CMCC - Centro Euro-Mediterraneo sui Cambiamenti Climatici has been involved in several projects related to marine litter and plastics in the past, in particular during the projects DeFishGear (2016), AMAre (2019), NeCCton (till 2025).

The first study presented here focuses on the Adriatic Sea (Liubartseva et al., 2016). The particles distribution has been computed in 2 steps. In the first step, transition matrixes using ensemble runs (MEDSLIK-II, AFS currents, ECMWF wind) have been computed. In the second step Markov chains have been constructed to simulate the evolution over time of particle concentrations from terrestrial / maritime input. Particle half-life is ca 43 days in the Adriatic Sea (no accumulation). Larger surface concentrations are simulated in the Northern Adriatic part compared to the Southern part.

The second study focuses on the whole Mediterranean Sea. Fluxes onto the coastline are simulated rather than concentrations. Modelling floating marine debris in the Mediterranean have been computed using a 2D Lagrangian framework (Liubartseva et al., 2018). This study includes probabilities of washing and sinking, but no resuspension from the bottom is considered. The half-life of plastic originating from the coast is short for the Mediterranean Sea (7 days), while the half-life of plastics originating from shipping lines is longer (80 days). In a similar way, bottom fluxes are computed rather than bottom concentrations. Backtracking shows

that more than 50% of the plastics originate from their terrestrial inputs (rather than from shipping lines or foreign countries) for most Mediterranean countries.

Future plans include a one way coupling to the Biogeochemical Flux Model to take into consideration the interactions between microplastic and low trophic biota (PhD Angela Biancardi), and more specifically biofouling, the aggregation to marine snow and vertical transport by fecal pellets.

Discussion: is determining fluxes or concentration better? A reason advocating for fluxes is an easier comparison with measurements (beach cleaning, fluxes measured by sediment traps– an issue is, however, that sediment traps need to be specifically designed to collect plastics)

- Input data for litter modelling in the Black Sea (Svetla Miladinova, JRC)

The RIMMEL data has been used to provide anthropogenic litter input through rivers in the Black Sea. The largest input is through the Danube river. The model simulations are performed with Ichtyop particle model, without Stokes drift, and with particle bouncing (Miladinova et al., 2020). Surface concentrations have been determined. Two main data layers have been used to initialise the plastic fluxes to the ocean: watershed area and coastal population density. 4100 tonnes of microplastic are transferred into the Black Sea (37 % originate from the Danube, 30 % from Istanbul). A major problem is the in-situ data discrepancy, which reaches several orders of magnitude.

In a further step, the modelling of floating macrolitter from land-based sources has been performed with LTRANS-ZLEV. The number of items per surface has been computed. The floating litter amount is consistent with observations. Ship lines input have not been considered yet. A sensitivity test has been performed on whether increasing the transfer rate of particles into the ocean (150 particles/day vs 40 particles /day) and has shown that the final distribution is not impacted. Another sensitivity test has been performed to assess the role of seasonality by performing a constant and seasonal release at the Danube location. The seasonality may have a large effect close to the source, but less on the remote particle distribution.

Discussion: The contribution of the shipping source of plastic can be obtained using a random release by shipping lines (available on EMODnet). In the Black Sea, 20% of plastic may originate from vessels. Is the Sea of Azov a big source of plastic? In general, the amount of plastic waste is very high in the Bosphorus

- Fram Pollution Observator (Mine Tekman)

A long-term observatory (Hausgarten) has been installed west of Svalbard. It provides sustained time serie at 21 fixed locations along an ice and bathymetry gradient (250 – 5500 m) to provide a comprehensive overview of the litter fluxes. A general increase of litter has been observed since 2002.

Macrolitter are collected by beach clean-up (20 beaches) / visual survey (276 transects) / seafloor imaging (26 transects). On the beaches a total of 1620 Kg of litter have been collected (370.000 items/km2). Fisheries related items constitute 87 % of the mass, but general plastics (packaging, etc...) dominate the abundance. Identifiable debris (2%) originate from the Arctic (47 %), European regions (32 %) or very distant places (6 %). Sea surface shows a median concentration of 11 items / km2. Litter were about 4 times higher in summer than in other seasons, possibly due to the increase of marine / tourism activity. Litter concentration is negatively correlated with wind speed and nearest distance with the European coastline. Debris concentration increases on the seafloor, where 500 times higher concentrations on the seafloor (4571 items/ km²) than at the surface are observed. Small debris dominated the seafloor and medium size dominate at the surface. Results are available in Tekman et al. (2022). The results from Litterbase are consistent with observations. Microplastic show highest concentrations at the surface (218 item km-2 surface vs 60 in the water column). Small scale circulation features are important. Much more particles are present in sediments (190.000 items.km-2) compared to water column. Highest levels are measured in sea ice and snow (1.4e6 items.km-2)

A Lagrangian model showed that particles can travel up to 600 km above the seafloor while sinking (sinking speed about 10-50 m/day). An important question is what the interactions with biota and biogeochemical cycles are. Up to 31 % of the organisms interacted with debris on the deep seafloor at the Hausgarten observatory (ingestion by zooplankton: a total of 64 plastic fragments were detected in 1417 individuals). Microplastic has been found in ice algaes, which could be a transportation vector.

Discussion: Which statistical distribution should be assumed (mean vs median)? Is the distribution following a normal law? At global scale, a scientific question is whether there may be a link with the global circulation due to water mass formation.

- Plastics inputs to the Mediterranean Sea. Blue2 – modelling framework (Diego Macias, JRC)

JRC performed Lagrangian tracer experiment in the Mediterranean Sea. Litter releases are obtained using most recent estimation based on Gonzales Fernandez et al., (2021) using population, percent of mismanaged waste (EEA/Eurostat) and riverine observations (RIMMEL project). The Lagrangian Model LTRANS-Zlev (presentation Celia Laurent) has been used. The model experiments have been run for 150 days (the half-life of litter presence is about 90 days) on the period 2016 – 2018 (ERA5 atmospheric forcings). The particles have been grouped into „super individuals ". 33 sub areas are defined.

After 150 days, 10% of the particles were estimated to be still floating, while the remaining 90% were beached. The resulting floating macroplastic mean concentration is about 9 items/km2, which is consistent with observations and other model estimates (15-25 items/km2). The beached macrolitter is spatially correlated with monitoring data. However, the modelled values are lower by 2 orders of magnitudes (1800 items/100m in observations compared to 16.5 items/100m in model experiments). A possible reason for the discrepancy with observations could be related with the underestimation of macrolitter inputs since the model does not consider plastics from marine sources. The latter includes sources from maritime traffic and in particular small fishing vessels (but there is a lack of measures in the southern part of the Mediterranean Sea from these two sources). An issue is how to estimate litter production per vessel for different types. Other potentially important sources which are currently overlooked are aquaculture and fish farming. Another potential cause of the discrepancy between model and observations is the accumulation over time reflected in the later (at least 3 months in the MSFD monitoring data) and not considered in the models (which reflect more the flow of litter from the sea to the land).

Open questions should other land-based sources be considered. Could wind and dust deposition transport litter especially from the southern part of the Mediterranean Sea (waste mismanagement). Does resuspension from sea sediments play a significant role?

4 Session 3 (day 1): Existing gaps and model validation

This session comprises 3 presentations:

- Textile microfibres in the marine environment (Giuseppe Suaria, CNR)

A microplastic sampling campaign showed very low concentrations of plastic particles in the Southern Ocean, around Antarctica. However, a significant number of textile fibres have been found. Further cruises have shown a negative correlation between fibres concentrations and latitude. Textile fibres are also generally more abundant at the sea-surface than in the water column.

These fibres have a median length of about 1 mm and a diameter of about 15-18 µM (typical of textiles). Most fibres are organic and of natural origin (cotton/wool), only 8% being synthetic. Some difference in concentration exists between different ocean basins. A global estimation is 0.2-1.1 x 10e18 floating fibres, which is in terms of weight, similar to estimates of floating plastics (86-386 thousand tons). This represents about 0.1% of the global textile fibre production, which has almost doubled in the last 20 years. It is surprising that only 8% of fibres present in the ocean are synthetic fibres, despite synthetic fibres currently dominate global textile production. Hypotheses include a higher shredding of natural fibres as well as a historical dominance of their use which led to their accumulation in the marine environment. Dyes and additives may also stabilise fibres and prevent them from decaying. The degradation of textile fibres is very slow in seawater. Most fibres are likely provided by atmospheric deposition (multiple diffusive sources) rather than wastewaters.

Understanding the origin/fate of fibres is a clear knowledge gap, and it is needed to quantify the fibres' fluxes (sediment traps, etc.). Fibres are often considered microplastic particles and may constitute 80-90% of total microplastic counts. The assumption that most of these fibres are synthetic may lead to overestimating microplastic abundance in natural ecosystems. Fibres should be considered a distinct class of contaminants, since they have different sources, properties, and impacts if compared to secondary microplastics.

Discussion: how to consider these fibres and whether they are microplastics. Their degradation time largely depends on local conditions, organisms and, ultimately, nutrient concentrations. Degradation tests are performed in the laboratory. Cellulose can become refractory. The long-term fate of synthetic fibres is unclear (fractionation?)

- Litterbase.org: an online portal for Litter and Microplastics and their impacts on Marine Life (Mine Tekman)

The number of publications focusing on marine litter has increased exponentially since 1980. Litterbase.org is based on data extraction from peer-reviewed publications. It contains more than 3000 publications at 18666 locations and reports interactions of marine litter with 4527 species. A global map of marine litter distribution is shown in litterbase.org, which can be filtered by reporting unit, sampling year, size category, and habitat studied. A global map on the impacts of marine litter on biota is also available: interaction type (ingestion, entanglement, colonisation), aquatic system, and species habitat. There have been many requests for data sharing. A collaboration with WWF Germany for the report entitled "Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystems" received substantial attention by the media pointing out the importance of an international legally binding agreement for combatting plastic pollution (UNEA-5.2) (Tekman et al., 2022). This report includes global analyses of LITTERBASE data. The challenges associated with LITTERBASE are -sustainability of the database and data sharing policy (copyright issues). At the moment, it is not possible for scientists to directly enter the data. A new version is envisioned to tackle these issues

- Model observation comparison Mediterranean Sea (Diego Macias, JRC)

The focus of the study is to validate model outputs of beached litter in the Mediterranean Sea for the period 2016 - 2018. The JRC model framework has been used. The spatial correlation between the model and MSFD data is 0.4, which is relatively high. However, mean model data is 2 orders of magnitude lower (16.5 items / 100m) compared to the mean MSFD value (1800 items / 100m). Comparing model data with another dataset

(MLW (EEA)) shows a lower correlation. This dataset, however, displays a lower mean number of items (700 items / 100m).

This example clearly highlights the need to define a strategy to compare models and observations. In particular, one has to reply to the following questions: what are the requisites for datasets to be usable? What are the unavoidable differences between monitoring and model data? Which datasets are available?

5 Session 4 (day 2): High trophic level modelling

This session comprises 6 presentations focusing on risk assessment, food webs and higher trophic levels.

- Marine Litter and microplastic abundance in the Marine Environment and their impact on marine biodiversity (Montserrat Compa, IEO-CSIC)

The discussed modelling framework combined marine litter models, empirical data on marine litter and ingestion rates in marine species, with models combining the two to assess spatial risk of species encountering plastic debris.

The estimation of the distribution of Marine Litter is based on the model WMOP (2 km resolution – 2009-2016) (Juza et al., 2016; Mourre et al., 2018). It includes land-based sources (river inputs, population) and marine-based sources (marine traffic). Stokes drift comes from the Copernicus Marine Service wave model. These model simulations are complemented by "in situ" measurements performed in the western part of the Mediterranean Sea. Microlitter in the water column is mainly constituted by fibres (96%) with an abundance of microliter that is higher at intermediate distances from the coast (5-10 km), with mean values of 2.4/+-1.9 items (Rios-Fuster et al., 2022). During the Plastic Busters MPAs project (https://plasticbustersmpas.interreg-med.eu), litter was analysed from the sea surface to the seafloor in Cabrera National Park. MPAs and non-MPAs analysed presented similar microlitter abundance on the sea surface although no significant differences were observed between the water column and hyperbenthos. Macrolitter in MPAs is present on the seafloor (majority artificial polymers followed by wood/glass). Of the items collected with identifiable sources, it originates mostly from tourism (37%) and fisheries (8%). In terms of biota, analyses show that about 50% of fishes (70% of shellfish) contain microplastics within the MPA. Microplastic composition includes high-density, e.g. polyethyelene, polypropylene (surface, sediments), and low-density polymers, e.g. polyethylene and cellulose acetate (biota). Specific traits (e.g. predation behaviour) of individuals are important (Compa et al., 2022) to determine the distribution and fate of microplastics in the biota (e.g. ingestion of fibres vs fragments).

In a further step, a Mediterranean risk assessment for plastic ingestion has been performed across many marine species (Compa et al., 2019). The risk of ingesting plastic pollution ranges from 0.7 to 53. High-risk areas are located in both the eastern and western Mediterranean Sea, especially along the Spanish Mediterranean Coast and the northern African Coastline. A specific assessment has been performed for the Balearic Islands and the Cabrera National Park (specific maps for benthic, nektobenthic and pelagic species) (Compa et al., in progress). It has been possible to determine a mean risk for different compartments.

The next steps include the consideration of life history traits taking into account the bioavailability of types of microplastics and accumulation location, how plastic affects population and community levels and the residence time of plastics in each compartment.

Discussion: It appears in this study that the risk of ingesting microplastic is apparently much lower in the Black Sea compared to the western Mediterranean, possibly due to a lack of observations in the Black Sea. The large accumulation in mussels could be due to both a large accumulation effect and a very fast transit time. How much is too much (risk)? Different species display different responses to the same exposure.

- Exploratory Project – Plastic Web: Tracing microplastics up the EU marine food webs: implications for marine biodiversity and EU ecosystems service (Chiara Piroddi, JRC)

Plastic production in the EU increased from 1950 to 2000, remaining stable (60 MT) afterwards. Consumption represents 15 % of the total global production. 90 % of marine plastic is microplastic (items < 5 mm). Several policies targeted plastic pollution (1991: Urban Waste Water Treatment Directive, 2008: Marine Strategy Framework Directive – Waste Framework Directive, 2011: Biodiversity Strategy for 2020, 2018: Plastic Strategy, 2020: Biodiversity Strategy for 2030, 2021: Zero Pollution Action plan, 2022: Nature Restoration Law (proposal))

A complex modelling framework (Land / Rivers / Marine / Biogeochemistry / Food web) has been used to support policies (Blue2MF: mcc.jrc.ec.europa.eu). Case studies have been performed for the Mediterranean and Black Seas. These basins are semi-enclosed and display a large retention of plastics particles (respectively, 21 and 54 % of all marine floating plastics).

The objectives of the Plastic Web project are to create a database, to assess the effect of plastic pollution on ecosystems, to quantify species and groups affected by plastic pollution and test scenarios (future without action / 10 % reduction microplastic / 50 % reduction). The tools available include 3D ocean circulation models, permitting to map the distribution of ocean properties and plastics, as well as Food Web models aiming to understand impacts on higher trophic levels. These latter models use the data generated by the 3D ocean circulation models.

Discussion: as a note of caution, one should keep in mind that the Black Sea is characterized by large anoxic regions.

- Ecopath, Ecosim, Ecospace (general introduction) (Natalia Serpetti, JRC)

Different types of models are used to gain insight into the functioning of the marine environment. They include ocean circulation (e.g NEMO), ocean biogeochemical cycles (e.g ERSEM), size-based organism models (e.g MIZER), food webs models (e.g Ecopath with Ecosym - EwE) and system models (e.g ATLANTIS). The high trophic levels modelling at JRC uses EwE. This modelling framework is based on different modules: Ecopath (static mass-balanced model), Ecosim (temporal dynamics), and Ecospace (spatial-temporal dynamics). Ecotracer : is a complementary module, which tracks persistent pollutants.

Here several models are introduced as an example of this approach. The Black Sea Ecopath model, recently updated, contains a large number of functional groups (44) and includes 5 trophic levels (3 dolphin species, 1 seabird group, 26 fish groups, 6 invertebrates, 2 zooplanktons, 3 primary producers). The low trophic levels properties are provided by GETM-BSEM in the case of the Black Sea. Ecopath is a mass-balanced model. The evolution of the mass in each compartment is given by the general differential equation: dC/dt = Production + Net Migration + Yield – Respiration – mortality – predation. The "best" parameters are used to parameterize the processes and replicate observations (time -series) and environmental niches. An example of applications is the impact of climate change on species distribution using future temperature distribution based on climate models and temperature tolerance of species.

Ecospace is spatially resolving. It uses input fields from ocean circulation models (such as temperature, primary production, oxygen). An example of the Ecospace application is to understand the effects of the implementation of Fisheries Restricted Areas in the Adriatic Sea in a climate change context.

- Modelling microplastics in the ecosystem with Ecotracer (William Walters, Penn State Univ.)

Ecotracer was developed in the early 2000s and has been used in many applications over the years, e.g. to assess several pollutants, such as methylmercury, dioxin, C14, chemical warfare agents, and Polycyclic Aromatic hydrocarbons. It has been recently used for microplastics.

Pollutant transfer between compartments (from the environmental to the biological compartments) is possible through environmental inflow, direct uptake, predation, and immigration. Losses are outflow, excretion, and mortality. The species' direct uptake is assumed to be proportional to the environmental concentration and the species' biomass. From a general point of view, a fraction of the contaminant ingested reaches the digestive tract, as some pollutants can be accumulated in the species' tissues. For microplastic, we assumed no accumulation; therefore, microplastics are "retained" in the digestive tract until excretion. Excretion rates should therefore refer to the rate at which the plastic passes through the digestive tract, which is generally very fast, on the order of a day or less. The contaminants can be excreted from the biota back into the environment. Contaminants may also be metabolised into an inert form or undergo physical decay—contaminant flow in or out of the environment. The major challenge is to parameterise these processes. Some parameters can be determined by performing laboratory experiments. Parameters can also be chosen such that observed microplastic concentrations are reproduced numerical equilibrium of the Ecotracer modelm.

Different sets of equations specific for each class of microplastics need to be implemented, as there are strong variations in the biological and physical behaviour along size (10 to 1000 micrometres) and shape of microplastics (e.g. sphere vs fibres). An issue is that the parameter tuning requires a lot of high-quality data for each species, and these data are currently missing.

Another challenge is to take into account physiological processes. Multiple compartments may be needed within a species to better simulate fast vs slow release. The transfer from the environment to the digestive tract is fast, while the transfer from the environment to the tissue is slow. In some cases (small microplastics), a transfer may occur from the digestive tract to the tissue. Finally, the distribution of plastics in the environment depends on the temporal/spatial water flow, which can be obtained using a Lagrangian particle-tracking framework. Environmental concentrations generation by an external solver such as the Langrangian method can be transferred into Ecotracer using the spatial-temporal framework.

Discussion: A general challenge is that the number of parameters is very high. A way to minimise the uncertainty is to use different models or run ensemble models. Excretion rate, etc., should be universally applicable, while uptake rate is more challenging. Some parameters are "universal", and some are specific to species.

- PLASTIC-WEB: Tracing Microplatstics up the EU marine food webs (Natalia Serpetti, JRC)

The goal of the project Plastic Web is threefold: -create a database with data for models' construction (concentration, uptake rate), -assess microplastics pathways in the Mediterranean and Black Seas ecosystems, -quantify the species and areas mainly affected by plastic pollution (hot spots) and test future scenarios: no action, reduction by 10 % and 50 % of microplastics emission.

The database includes a total of 218565 individuals, 710 species, and more than 200 publications. A subset of 114.836 individuals were used for this analysis excluding large top-predators and benthic invertebrates. Statistical analyses were performed using general linear models with microplastic occurrence and mean micro-plastic particles per individual (response variables) in relation to log-transformed number of stomachs to assess differences in term of "location" and "habitat preferences" (explanatory variables). Higher occurrences are shown in specific places (Indian Ocean, China Sea) and ecosystems (mangrove, estuaries). No significant differences were found across different habitat preferences (Serpetti et al., 2022).

An important aspect is how the microplastic is redistributed into the ocean by ocean currents and whether microplastic distribution overlaps species distribution. The microplastic redistribution can be derived from Lagrangian studies and the impact on species can be assessed using EwE with Ecotracer. Ecotracer has been used to study microplastics distributions in only two scientific articles (Boyer et al., 2022; Ma and You., 2021) and none of them addressed spatial distributions.

Ecotracer contains 2 different types of compartments: environment and biomass. In the environment, the microplastic level results in a balance between gains (inflow and species excrections) and losses (outflow, decay rates, species uptake). For each biomass compartment, it results in a balance between gains from direct uptake from the environment and from indirect uptake from the food web and losses (fisheries, mortality). Ecotracer has been tested using a simple set up and a limited number of compartments (small zooplankton, large zooplankton and sprat). It has been calibrated using biological rates from publications and transport from Lagrangian particles. An issue when adding larger species is determining biological rates (e.g., excretion). A possibility is to use a statistical relationship 'excretion vs weight' but this is far from ideal.

Discussion: SB made a long comment / recommendation on the approach: SB advised to cut off the trophic level at 2.5 (focus on the species eating zooplankton) and divide them between benthic / free swimming organisms and only use excretion rates (no direct uptake) in higher trophic levels to test the propagation into the system (bottom-up approach). As a next step, the higher trophic levels should be parametrized based on observations. The rates in publications should be only guidelines as they may vary by one order of magnitude. It is better to separate microfibres and microplastics as they have different behaviours. General discussion: it is difficult to collect excretion for e.g., whales. A question is whether the relationship excretion / animal weight can be applied. A possibility could be to use a fixed number.

- Microplastic in the Maryland coastal bay (Shawn Booth)

The focus of this study is a small area (287 km2) in the state of Maryland, USA within Chesapeake Bay. This area contains 108 rare species and is close to Washington DC. Ecopath has been used and contains 21 groups and detritus. The model has been validated using in-situ data obtained from the Maryland Department of Nature Resources. The model has been fitted to a 1990-2017 biomass time series. Primary production is derived from chlorophyll time series in-situ data. Forcing functions have been used for salinity and temperature data. The response of groups to temperature and salinity is based on literature. Fishing effort is based on rescaled catch data.

Ecotracer simulations have been performed to assess future scenario of microplastic loadings. Ecotracer is based on a box model. For each compartment, the temporal derivative depends on biological and environmental processes. The Ecotracer model is specific for microplastics as one contaminant: in order to analyse different types of microplastics, a specific Ecotracer model would need to be implemented for each type/size of microplastic.

Three simulations scenarios have been performed from 2018 to 2090: 1)Increasing trends: tripling of microplastics every 30 years. This scenario shows an increasing trend from 200 to 1100 hundred percent for commercially important species, 2)Reduced inflow: linear decrease to 1990 levels, 3) Zero inflow: linear decrease to zero input.. The "reduced inflow" and "zero inflow" leads to a concentration peak around 2030. These two scenarios differ by the intensity of the decrease. "Zero inflow" displays similar concentrations in 2090 compared to 1990, while values are larger in "reduced inflow". Human dietary intake in microplastic for the "reduced inflow" and "zero inflow" shows 86 % and a 95 % reduction compared to the "increasing trends" scenario (Boyer et al., 2022)

Discussion: models are built for what generally happens, but they need to take in account "extreme events" too. Important is to remind that individuals are not modelled but groups, (i.e., the weight is of the group/population not of the individual) and to be aware of sampling bias. Taking into account effects on health (humans) needs to account for physiological processes and tissues concentration (e.g., the gut is generally not consumed)

6 Session 5 (day 2): Plastic modelling support to EU policies

Diego Macias discussed the relevance of plastic modelling in the definition of EU policies. The first focus is on beach litter threshold and transboundary issues. In 2020 an EU-wide agreement defined a threshold value of 20 items for 100 m of beach. A backward Lagrangian model has been used to determine the amount of litter originating from a local (same member state) and a remote source (other member state or outside the EU) in the Mediterranean Sea. The mean value for transboundary litter ranges for each member state from 30 % to 70 % (Macias et al., 2020).

A second focus is on the Zero Pollution ambition for litter, which aims to improve water quality by reducing water plastic litter at sea by 50 % by 2030. In order to define specific measures, it is necessary to understand the source of plastics and their distribution. Macroplastic estimates (Gonzalez et al., 2021) have been used for the Mediterranean Sea. The items have been transported using a Lagrangian model to determine coastal accumulation and ocean concentrations. Different test scenarios of plastic source decrease in the EU-waters have been envisioned (Single Use Plastic ban – reduce input by 60 % / perfect waste management – reduce input by 100 %). The improvement for the overall Mediterranean is a plastic reduction of 14 % (SUP ban) or 34 % (perfect waste management). It highlights the problem related to transboundary issues, especially regarding non-EU countries. International cooperation is needed to reach ambitious targets.

In order to ensure the highest standard in policy advice, it is needed to use the best framework available to provide information for all descriptors to the policy-making processes. It is a co-creation process with the scientific community.

7 General Discussions (day 1 and day 2)

Two general discussions took place at the end of the first and second days of the workshop. We merge and summarize these discussions here for clarity reasons. They emphasize very specific points that need to be considered in complement to the presentations. It has been agreed to write a "position" paper based on the discussions and presentations held during the workshop.

- Beaching

An issue related to beaching is the bias in data collection on beaches during the summer holidays season due to regular municipal beach cleaning and sand raking, which remove litter located on the surface of the substrate but also may cause the reappearance of buried litter. A possibility could be to access beaches closed to the general public. The MSFD monitoring guidance already consider this problematic as well to consider a mix of urban, semi-urban and remote beaches in the national monitoring programs. Modelling exercises could help choosing samples of beaches that fulfil these requirements.

From a modelling perspective, rocky and sandy beaches are parameterized identically. However, the stranding and washing off processes depend on the substrate. Differentiating different types of substrates is possible from a modelling perspective and for instance used in oil modelling applications. Geomorphology is detailed enough in the Mediterranean Sea. Model resolution is not an issue as the exact position of particles in Lagrangian modelling is known (conversely to Eulerian models, where the position is discretised). However, introducing additional model parameters without sufficient observational data to estimate these parameters may introduce further uncertainty. More in-situ measurements and studies focusing on beaching processes are needed.

- Vertical sinking velocities and biofouling

The general opinion is that one should use as few parameters as possible for biological processes, as otherwise it creates new uncertainties, which further propagate without benefit. An option is to focus solely on the sinking speed as it has the most important effect on microplastics. This sinking speed could be for instance parameterized as constant, increasing with time or depending on phytoplankton concentration. There is a need to do sensitivity tests in models.

- Overlooked processes and issues

The effect of floods and extreme events can carry a large amount of plastic in a short amount of time. This process is not linear and currently not taken into account in models. Resuspension in the water column is another process not taken into account although important, especially in tidally dominated shallow seas. The orientation of the coast and the wind direction may play a major role in the beaching process. Using different wind products (e.g ERA5 or coupled models) change the ocean circulation and may affect plastics distribution. As a note of caution, Lagrangian particles cannot be integrated for long period of time (e.g multiple years) as uncertainty increases over time. A strategy used previously to perform long term forecasts of oil dispersion is to assimilate observational oil data. This strategy is however possible only if sufficient observational data are available, which is rarely the case with plastic.

- Estimation of plastic input to the sea

An approach to estimate the global budget of microplastic could be based on circular economy data (estimation of how much plastic is not regenerated) although the question on how much reaches the ocean might still be open for discussion. Distinguishing primary or secondary microplastics is not an easy task due to a cascade of fragmentation processes. However, it is needed to better categorise the type and origin of plastic items. Most articles stress that fibres are dominant in terms of the number of particles. It would be useful to determine the share of sea-based (fisheries, aquaculture, shipping) origin, land-based (agriculture, construction, transportation on land, tourism) origin, and individual (packaging, textile, floating waste) origin. A problem is illegal releases from ships. Its contribution to plastic pollution depends on countries and legislations. A first estimate could be based on fishing grounds and ship density (e.g. using AIS data on vessel traffic). Another source of sea-based litter is tourism and recreational activities, which increase exponentially. They are not represented in EMODnet. An issue is that ship density is often based on AIS data, which is not used in smaller vessels.

- Statistical analyses

A question is whether mean or median should be used, in particular due to the presence of extreme events and outliers. A related remark is whether the measurements can be fully trusted. If this is the case, outliers should not be ignored as they may be caused by relevant processes (e.g. flooding events). It is not clear what the best solution to deal with data gaps in observations is.

- Dataset sharing and model validation

A way forward would be to merge available data to obtain the best state-of-the-art dataset possible. All groups should use the same data, in particular for data validation. A question is whether considering mass rather than items is a better approach. However, for small microparticles, computing mass may be challenging.

Databases are essential for finding efficiently and quickly relevant parameters or observations. However, the lack of funding may prevent efficient functioning. A solution could be integrating the current efforts into an existing database (e.g. EMODnet). A question is which type of data should be included in the database (raw or already processed data). An example of a database focusing on microplastics is currently developed by NOAA (https://www.ncei.noaa.gov/products/microplastics). Another example is being developed by the Ministry of the Environment, Japan (MOEJ). This "Marine Plastic Litter Monitoring Data Sharing Project" is focused on the harmonization of microplastics on the sea surface and is aiming at building a data sharing system (database) on harmonized microplastic data on a global scale which will be released in April 2023 (Isobe et al., 2021).

8 Summary and conclusions

This two-day workshop covered the different aspects of marine litter pollution. The first day focused on aspects related to litter characterization and circulation in the marine environment.

In the first part, Lagrangian models have been discussed. In this modelling framework the trajectory of a particle is traced, either forward (i.e., determine the particle destination) or backward (i.e. determine the particle origin) in time. The velocity field is provided by a traditional Eulerian model. Particles are driven by oceanic currents, but also by the waves (Stokes drift) and the wind strength (wind drag). As shown by Ove Parn, these three components are critical simulate the motion of a particle accurately and, therefore, where it will find its sink on the coast. In complement, the characteristics of a particle may evolve with time. For instance, it can undergo biological processes, such as biofouling, which modifies its density and buoyancy. These particles can be released in very large numbers, using specific tools taking advantage of computer parallelization (Celia Laurent). Thanks to the release of a massive number of particles, "hot spots" of accumulation, either offshore or on the coast, have been determined in the Celtic Sea (Tomasz Dabrowski) or the Mediterranean Sea (Kostas Tsiaras).

A large amount of work and sensitivity tests are still needed to parameterize the processes affecting the particles (biofouling, beaching, resuspension, fragmentation). Another very important aspect is to determine the sources of these litter particles. Estimation may vary, however, by several orders of magnitude. Extreme events, such as floods, may lead to a very high release rate in a short amount of time from the coasts into the ocean (Daniel González-Fernández). A possibility to better constrain litter distribution could be to focus on the rate of processes (e.g., beaching, sedimentation) rather than the end concentrations. This approach has been explored in the Adriatic Sea (Svitlana Liubartseva). Numerical sensitivity experiments, for instance to the particles release rate, permit to better determine the robustness of the results at different time scale, as shown in the Black Sea (Svetla Miladinova). More observations are needed. An example of a comprehensive observational framework is FRAM Pollution Observatory in the Arctic Ocean, as it provides multi-year observations at the surface, throughout the water column, on the seafloor, in sediments and on beaches (Mine Tekman). Compared to observations, some modelling studies (e.g in the Mediterranean Sea) display too low beached particles, suggesting that the amount of released particles is underestimated (Diego Macias).

Observations present, however, limitations. For instance, it has been recently found that microlitter is constituted by a high proportion of microfibers originating from textile material, with distinctive properties and behaviour (Giuseppe Suaria). Observations also need to be widely available, which is the ambition of the database Litterbase.org, containing data from more than 3000 scientific publications (Mine Tekman). A general discussion taking the case of the Mediterranean Sea (Diego Macias) followed, discussing in particular modelling aspects, such as the representation of processes affecting the particles and more observational aspects including data management.

The second day of the workshop focused on the impact of microplastics on marine organisms, food webs and higher trophic levels. Exposure and risk assessments have been performed in the Mediterranean Sea by combining plastic distribution and organism abundance (Montserrat Compa). The exploratory project PlasticWeb aims to assess the effects of plastic pollution on ecosystems and perform future projections (Chiara Piroddi). A modelling framework (Ecopath-Ecosim-Ecospace) based on mass fluxes can be used to assess the interactions between the food web and the environment. (Natalia Serpetti). This framework is completed by Ecotracer, a module specifically designed to simulate the mass transfer of a pollutant, such as microplastics, from the environment into the food web (Will Walters). It has been tested in the context of the PlasticWeb project, especially in the Black and Mediterranean Seas. One of the challenges is to parameterize the fluxes regulating the exchanges between the biological compartments and the environment, in particular for large species (Natalia Serpetti). Another regional example focuses on a water body characterized by the presence of commercial species and located close to a large urban area. The microplastic concentration potentially ingested by humans have been simulated in three different scenarios of microplastic environmental release (Shawn Booth).

In a conclusive part, the role of modelling in policy development has been highlighted. More specifically, Lagrangian backward integration permits to understand better the litter origin and transboundary issues in the Mediterranean Sea. The effects of different policies aiming to reduce waste discharge in the ocean have been tested (Diego Macias). The meeting ended by a final discussion, highlighting the need of more observational data and of a better understanding of plastic pollution sources and fluxes between compartments.

References

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G. W., Provencher, J. F., Rochman, C. M., van Sebille, E., and Tekman, M. B.: Plastic pollution in the Arctic, Nat Rev Earth Environ, 3, 323–337, https://doi.org/10.1038/s43017-022-00279-8, 2022.

Boyer, J., Rubalcava, K., Booth, S., & Townsend, H. (2022). Proof-of-concept model for exploring the impacts of micro-plastics accumulation in the Maryland coastal bays ecosystem. In Ecological Modelling (Vol. 464, p. 109849). Elsevier BV. https://doi.org/10.1016/j.ecolmodel.2021.109849

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., Po-gojeva, 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.

Isobe, A., Azuma, T., Cordova, M.R. et al. A multilevel dataset of microplastic abundance in the world's upper ocean and the Laurentian Great Lakes. Micropl.&Nanopl. 1, 16 (2021). https://doi.org/10.1186/s43591-021-00013-z

Laurent, C., Querin, S., Solidoro, C., and Canu, D. M.: Modelling marine particle dynamics with LTRANS-Zlev: implemen-tation and validation, Environmental Modelling & Software, 125, 104621, https://doi.org/10.1016/j.envsoft.2020.104621, 2020

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, https://doi.org/10.1038/ncomms15611, 2017.

Liubartseva, S., Coppini, G., Lecci, R., & Creti, S. (2016). Regional approach to modeling the transport of floating plastic debris in the Adriatic Sea. Marine Pollution Bulletin, 103(1–2), 115–127. https://doi.org/10.1016/j.marpolbul.2015.12.031

Liubartseva, S., Coppini, G., Lecci, R., and Clementi, E.: Tracking plastics in the Mediterranean: 2D Lagrangian model, Marine Pollution Bulletin, 129, 151–162, https://doi.org/10.1016/j.marpolbul.2018.02.019, 2018.

Ma, Y.-F., You, X.-Y., 2021. Modelling the accumulation of microplastics through food webs with the example Baiyangdian Lake, China. Sci. Total Environ. 762, 144110. https://doi.org/10.1016/j.scitotenv.2020.144110

Macias Moy D, Garcia Gorriz E, Stips A. Report on the Kick-off workshop of the Network of Experts for ReDeveloping Models of the European Marine Environment. EUR 27817. Luxembourg (Luxembourg): Publications Office of the Euro-pean Union; 2016. JRC100815

Macias Moy, D., Garcia Gorriz, E. and Stips, A., Report on the second workshop of the Network of Experts for ReDevel-oping Models of the European Marine Environment, EUR 28810 EN, Publications Office of the European Union, Luxem-bourg, 2017, ISBN 978-92-79-73898-2, doi:10.2760/221355, JRC107964.

Macias Moy, D., Piroddi, C., Garcia Gorriz, E. and Stips, A., Report on the third workshop of the Network of Experts for ReDeveloping Models of the European Marine Environment, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97260-7, doi:10.2760/80960, JRC113544.

Macias Moy, D., Friedland, R., Piroddi, C., Miladinova-Marinova, S., Parn, O., Garcia Gorriz, E. and Stips, A., Report on the fourth workshop of the Network of Experts for ReDeveloping Models of the European Marine Environment, Publica-tions Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-14270-6, doi:10.2760/72854, JRC119257.

Macias, D., Cózar, A., Garcia-Gorriz, E., González-Fernández, D., and Stips, A.: Surface water circulation develops sea-sonally changing patterns of floating litter accumulation in the Mediterranean Sea. A modelling approach, Marine Pol-lution Bulletin, 149, 110619, https://doi.org/10.1016/j.marpolbul.2019.110619, 2019.

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

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

Miladinova S, D Macias Moy, A Stips, E Garcia-Gorriz: Microplastics accumulation on the Black Sea coast: Scenario analysis - Marine Litter in the Black Sea, TUDAV, 56, Istanbul, Turkey, 2020 b

Piroddi, C., Akoglu, E., Andonegi, E., Bentley, J. W., Celić, I., Coll, M., Dimarchopoulou, D., Friedland, R., de Mutsert, K., Girardin, R., Garcia-Gorriz, E., Grizzetti, B., Hernvann, P.-Y., Heymans, J. J., Müller-Karulis, B., Libralato, S., Lynam, C. P., Macias, D., Miladinova, S., Moullec, F., Palialexis, A., Parn, O., Serpetti, N., Solidoro, C., Steenbeek, J., Stips, A., Tomczak, M. T., Travers-Trolet, M., and Tsikliras, A. C.: Effects of Nutrient Management Scenarios on Marine Food Webs: A Pan-European Assessment in Support of the Marine Strategy Framework Directive, Front. Mar. Sci., 8, https://doi.org/10.3389/fmars.2021.596797, 2021.

Pärn O, Davulienė L, Macias D, Vahter K, Stips A, Torsvik T. Effects of Eulerian current, Stokes drift and wind while simulating surface drifter trajectories in the Baltic Sea. Oceanologia. https://doi.org/10.1016/j.oceano.2023.02.001, 2023.

Suaria, G., Achtypi, A., Perold, V., Lee, J. R., Pierucci, A., Bornman, T. G., Aliani, S., and Ryan, P. G.: Microfibers in oceanic surface waters: A global characterization, Sci. Adv., 6, https://doi.org/10.1126/sciadv.aay8493, 2020.

Serpetti, N., Walters, W.J., Piroddi, C., Garcia-Gorriz, E., Miladinova, S., Macias Moy, D., 2022. Tracing microplastics up the EU marine food webs: implications for marine biodiversity and EU ecosystem services (PLASTIC-WEB): Uptake of plastic by marine organism's database (No. JRC130033). JRC - European Commission, Ispra, Italy.

Tekman, M. B. , Walther, B. A. , Peter, C. , Gutow, L. and Bergmann, M. (2022): Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystems, 1–221, WWF Germany, Berlin. Doi: 10.5281/zenodo.5898684

Tsiaras, K., Costa, E., Morgana, S., Gambardella, C., Piazza, V., Faimali, M., Minetti, R., Zeri, C., Thyssen, M., Ben Ismail, S., Hatzonikolakis, Y., Kalaroni, S., and Garaventa, F.: Microplastics in the Mediterranean: Variability From Observations and Model Analysis, Front. Mar. Sci., 9, https://doi.org/10.3389/fmars.2022.784937, 2022.

van Emmerik, T., de Lange, S., Frings, R., Schreyers, L., Aalderink, H., Leusink, J., Begemann, F., Hamers, E., Hauk, R., Janssens, N., Jansson, P., Joosse, N., Kelder, D., van der Kuijl, T., Lotcheris, R., Löhr, A., Mellink, Y., Pinto, R., Tasseron, P., Vos, V., and Vriend, P. (2022a). Hydrology as a driver of floating river plastic transport. Earth's Future, 10(8):e2022EF002811.

List of abbreviations and definitions

AFS : Adriatic Forecasting System

ATLANTIS: end-to-end model of marine ecosystems

Blue2MF : Blue 2 Modelling Framework

BSEM The Black Sea low trophic level Ecosystem Model

CETMAR : Foundation Technological Center of the Sea in Spain

CLAIM : project Cleaning Litter by developing and applying innovative methods in European Seas

ECMWF : European Centre for Medium-Range Weather Forecast

EEA : Environmental European Agency

EMODnet : European Marine Observation and Data Network

ERSEM : European Regional Seas Ecosystem Model

EU : European Union

EwE : Ecopath with Ecosim

GETM General Estuarine Transport Model

ICES : International Council for the Exploration of the Sea

ichthyop : Particle tracing model(https://ichthyop.org/)

INTERREG: series of programmes to stimulate cooperations between regions in and out the European Union

JRC : Joint Research Center

LTRANS_Zlev: Lagrangian particle tracing model (https://github.com/inogs/LTRANS_Zlev)

MEDSLIK-II : Oil spill model

MEME : Network of Experts for ReDeveloping Models of the European Marine Environement

MIZER : size-based ecosystem model

MLW : Marine Litter Watch

MOEJ : Ministry of Environment Japan

MOHID : water Modelling System

MPA : Marine Protected Area

MRU : Marine Reporting Unit

MSFD : Marine Strategy Framework Directive

NEMO : ocean model Nucleus of the Ocean

NOAA : National Oceanic and Atmospheric Administration

OILTRANS : oil spill model

OSPAR : Oslo and Paris Conventions

RIMMEL: JRC Exploratory Research Project. It started November 2015 and had a duration of 24 months.

ROMS Regional Ocean Modelling System

SWAN : ocean wave model

UNEA 5.2 : United Nation Environmental Assembly 5

UNEP : United Nation Environmental Programme

WWF : World Wild Fund

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Annexes

Annex 1. List of participants

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Annex 2 : Current understanding of processes related to litter distribution

Table 1: processes related to litter distribution

	Observations / knowledge	Model (implementation /realism)
Processes (individual particle)		
Transport by currents		
Stokes / wind drift		
Beaching		
Washing off		
Sinking / biofouling		
Fragmentation		
Resuspension		
Ocean circulation (large number of particles)		
Hot spots (open ocean)		
Hot spots (coast)		
Variability		
Climate change		
Pollution sources		
Rivers		
Diffuse coastal		
Marine sources		
Atmospheric sources		
Variability and extreme events		
Long term evolution		
Food webs and ecosystem		
Lower trophic levels		
Higher trophic levels		
Risk assessment		
Metabolism and physiology		
Impact on Human health		

Green: relatively good understanding / implemented
Orange: some level of understanding / implemented but not necessarily realistic
Red: poor understanding / not implemented / not realistic

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