State-of-the-art modeling the interaction between microplastic and the low-trophic level marine biota

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Introduction

Microplastic is ubiquitous in marine environments poses a significant threat to the health and well-being of marine organisms and the ecosystems they rely on.
The objective of this work is present a contemporary overview of existing models, both the Lagrangian and Eulerian ones; focusing on model-based coupling microplastic (MP) and the low-trophic level (LTL) marine biota.

##	Domain (Reference)	MP model	Coupled LTL model	Transport of MP	Interaction with sediments	Coupling of MP with biota and possible climate implications		
						Biota influences MP (coupled variables)	MP influences biota	Climate projections
1	Any domain (Kooi et al., 2017, Kreczak et al., 2021)	1D Lagrangian	n/a	Gravitational settling	n/a	Algal biofouling (chl-a)	n/a	n/a
2	Global ocean (Lobelle et al., 2021)	3D Lagrangian, PARCELS	MEDUSA	3D advection, Gravitational settling	n/a	Algal biofouling (diatoms, non-diatoms)	n/a	n/a
3	Global ocean (Fisher et al., 2022)	1D Lagrangian PARCELS	MEDUSA	Vertical turbulent diffusion, gravitational settling	n/a	Algal biofouling (TPP, diatoms, zooplankton)	n/a	n/a
4	Mediterranean Sea (Guerrini et al., 2023)	1D Lagrangian, PARCELS	MEDUSA	Gravitational settling	n/a	Algal biofouling (TPP, diatoms, zooplankton)	MP-mediated loss of phytoplankton, loss/ gain of DIC, gain of POC	Possible amplification of carbon export
5	Mediterranean Sea (Tsiaras et al., 2021, 2022)	3D Lagrangian	n/a	3D advection, and turbulent diffusion, gravitational settling	Retention, washing off and burial of MP on the beach	Bacterial biofouling	n/a	n/a
6	Global ocean (Kvale et al., 2020, 2021, 2022, 2023)	3D Eulerian	Fully embedded in UVic ESCM	3D advection, and turbulent diffusion, gravitational settling	Seafloor deposition/ resuspension	MP export by marine snow and zooplankton fecal pellets	MP-mediated decrease in zooplankton grazing pressure	Possible growth in oxygen demand
7	Oslo Fjord (Berezina et al., 2021)	2D Eulerian	Fully embedded in 2DBP	2D advection, and turbulent diffusion, gravitational settling, relaxation to climatic data	2D transport in upper sediments	Algal/bacterial biofouling, zooplankton uptake, aggregation with POM	n/a	n/a

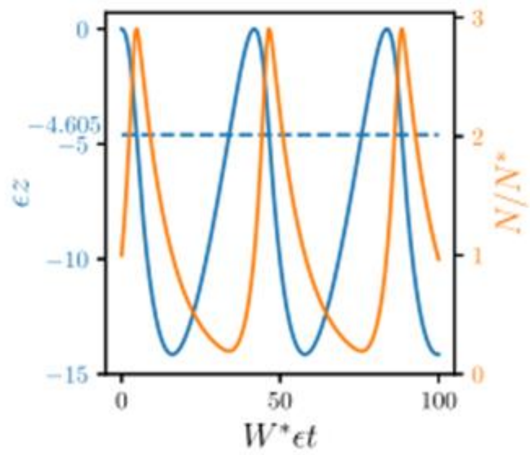
PARCELS: a set of Python classes and methods to create customisable particle tracking simulations using output from ocean circulation models (Delandmeter and Van Sebille, 2019); MEDUSA: a biogeochemical model of the marine carbon cycle (Yool et al., 2013); UVic ESCM: the University of Victoria Earth System Climate Model (Weaver et al., 2001); 2DBP: the 2-Dimensional Benthic-Pelagic model (Bruggeman and Bolding, 2014). TPP: total primary productivity; DIC: dissolved inorganic carbon; POC: particulate organic carbon; POM: particulate organic matter.

Governing Equations

Lagrangian framework	Eulerian framework
$dX(t) = dX_{adv}(t) + dX_{diff}(t) = u(x,y,z,t)dt + dX'(t)$ $dY(t) = dY_{adv}(t) + dY_{diff}(t) = v(x,y,z,t)dt + dY'(t)$ $dZ(t) = dZ_{adv}(t) + dZ_{diff}(t) + dZ_{own}(t) = w(x,y,z,t)dt + dZ'(t) - w_{own}(t)dt$	$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + (w + w_{own})\frac{\partial C}{\partial z} - \frac{\partial}{\partial x}\left(K_H \frac{\partial C}{\partial x}\right) - \frac{\partial}{\partial y}\left(K_H \frac{\partial C}{\partial y}\right) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C}{\partial z}\right) = R_{sources} - R_{sinks}$

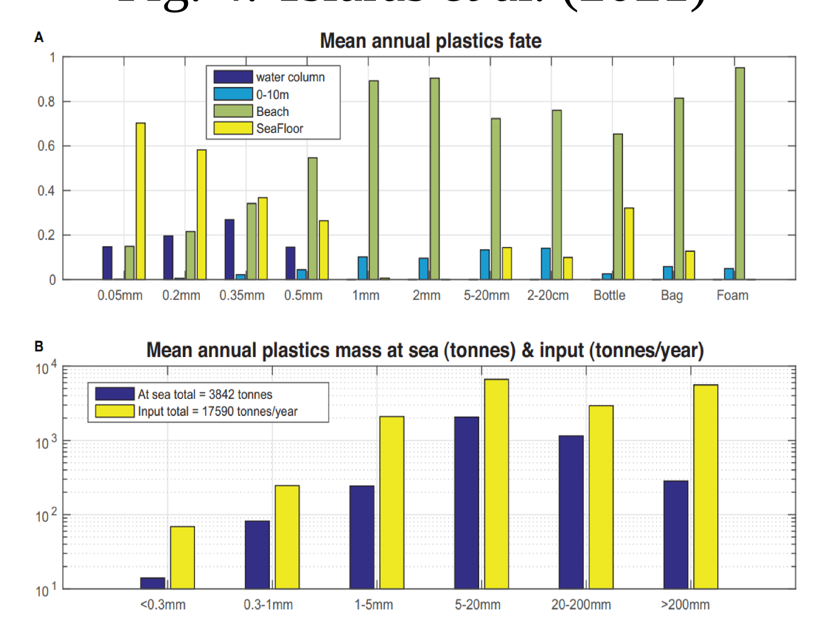
Result overview

Fig. 1: Kreczak et al. (2021)



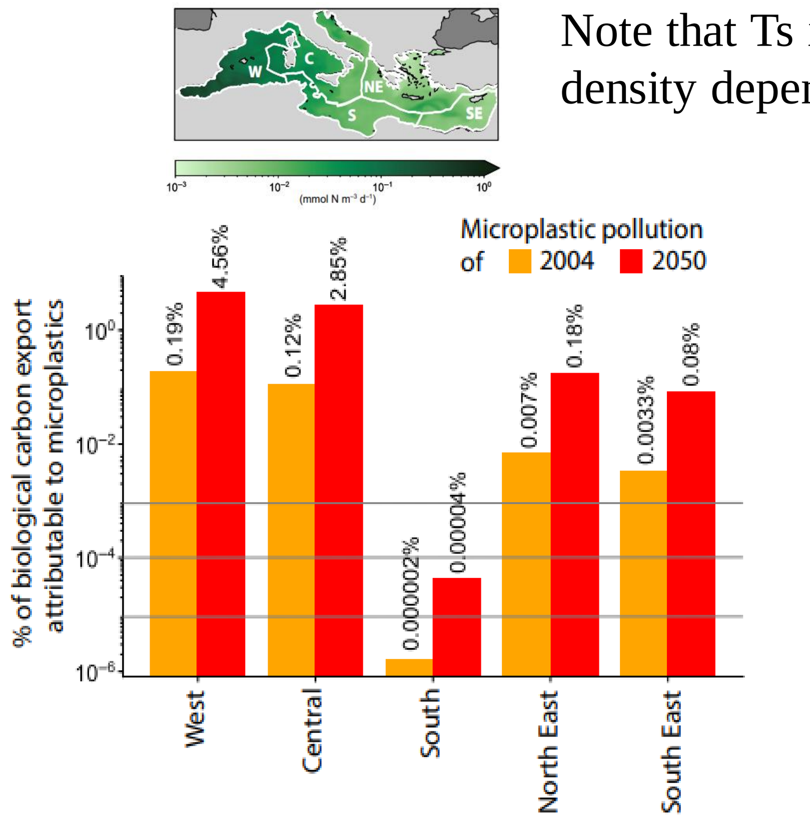
The time evolution of particle vertical displacement and the algal population are shown in blue and orange, respectively. The dashed line shows when the particle crosses the boundary of the euphotic zone. The results suggest that a higher conc. of biofouled MP is expected to be found subsurface, trapped close to the euphotic-zone depth rather than at the ocean's surface.

Fig. 4: Tsiaras et al. (2021)



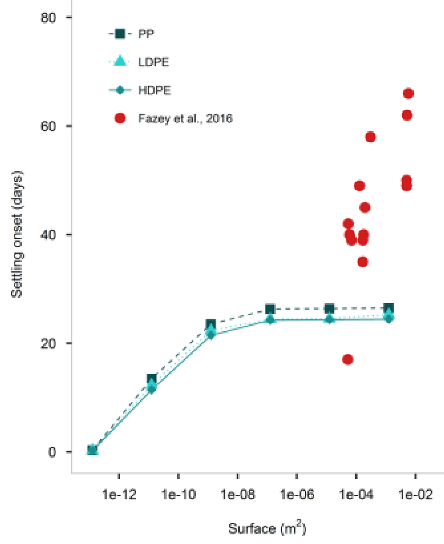
Mean (2010–2017) model simulations of the Mediterranean plastic and MP distributions.

Fig. 7: Guerrini et al. (2023)



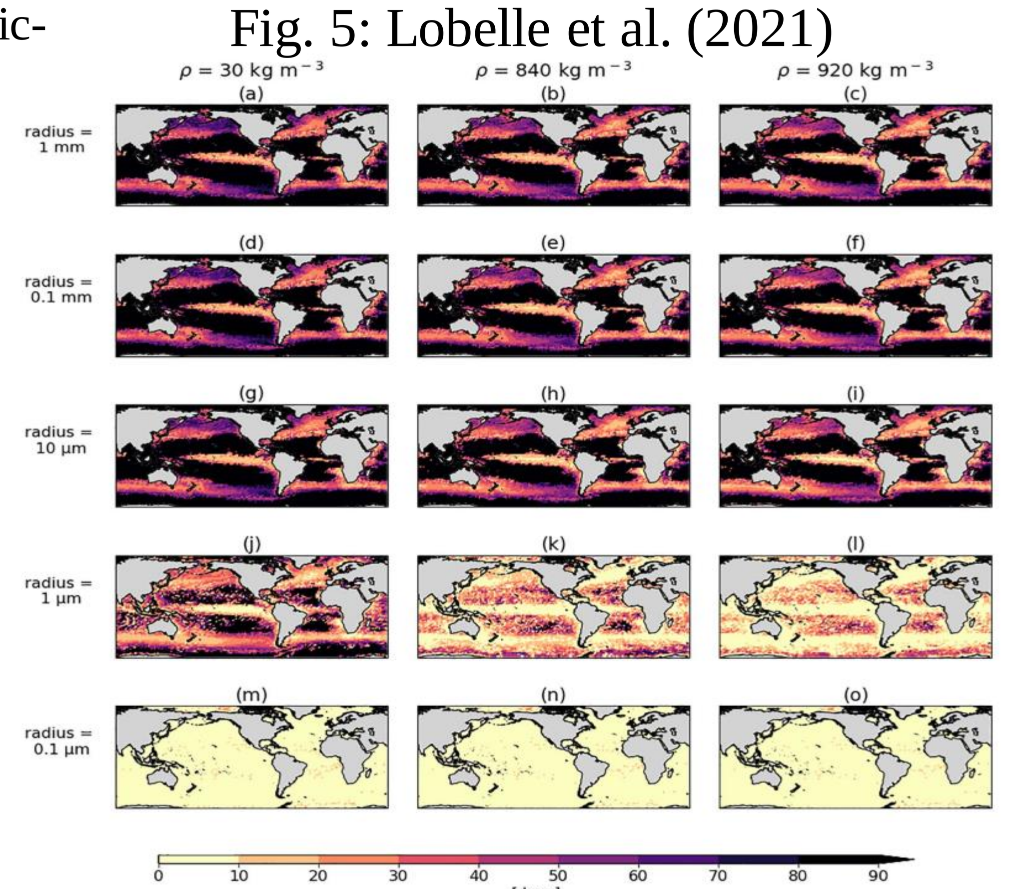
For the first time, the fraction of the total yearly POC export below 100 m, that can be attributed to MP in each of the five regions of the Mediterranean Sea.

Fig. 2: Kooi et al. (2017)



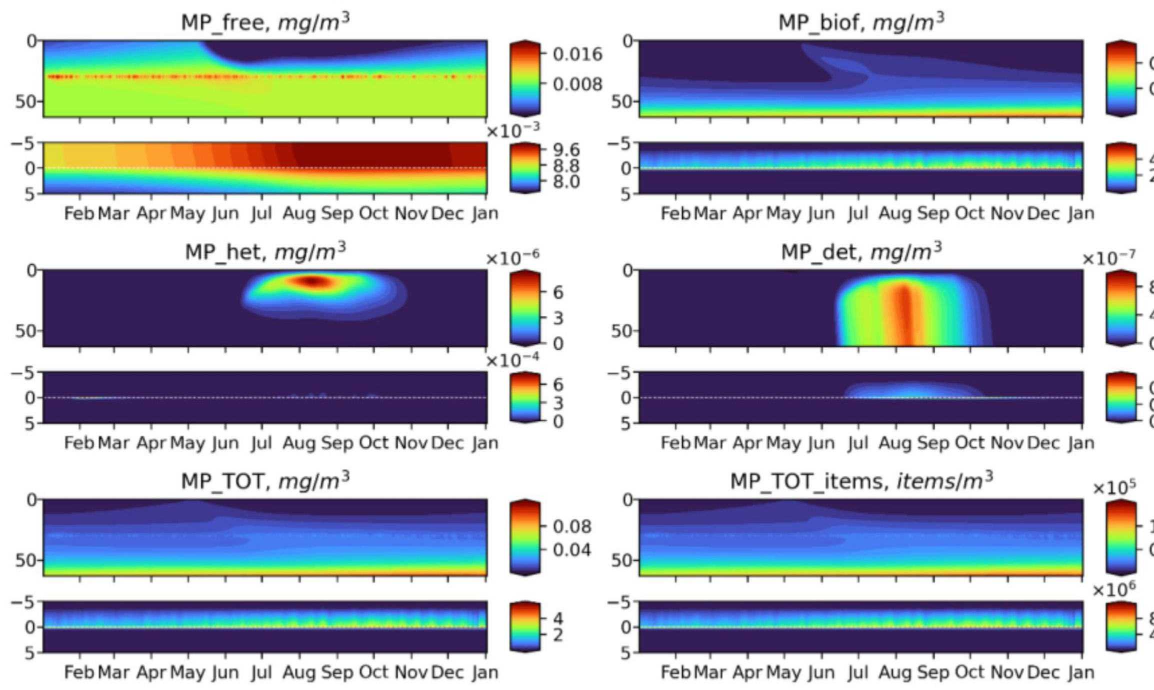
Denser particles start settling sooner compared to less dense particles when they are of the same size. In red, the results of a field study on the PE particles.

Fig. 5: Lobelle et al. (2021)



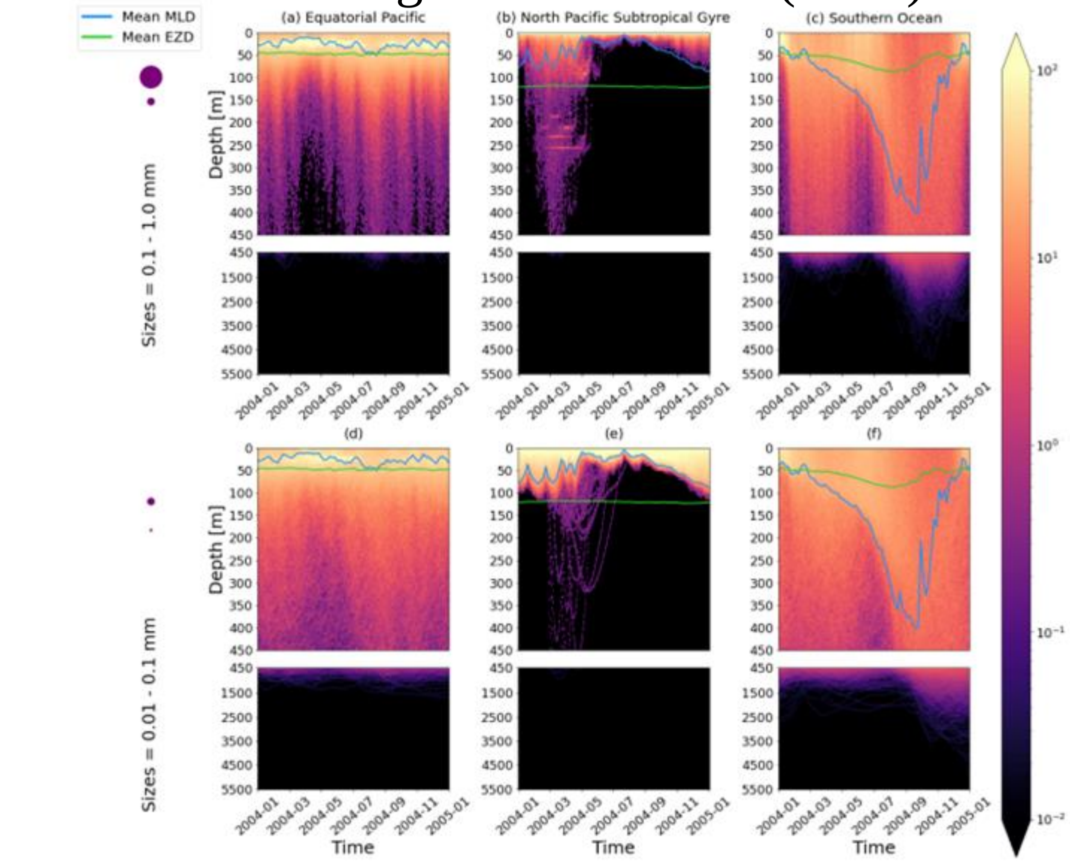
The sinking timescale, Ts (days) over simulations of 90 days for MP of different sizes and densities. Note that Ts is largely size-dependent as opposed to density dependent.

Fig. 3: Berezina et al. (2021)



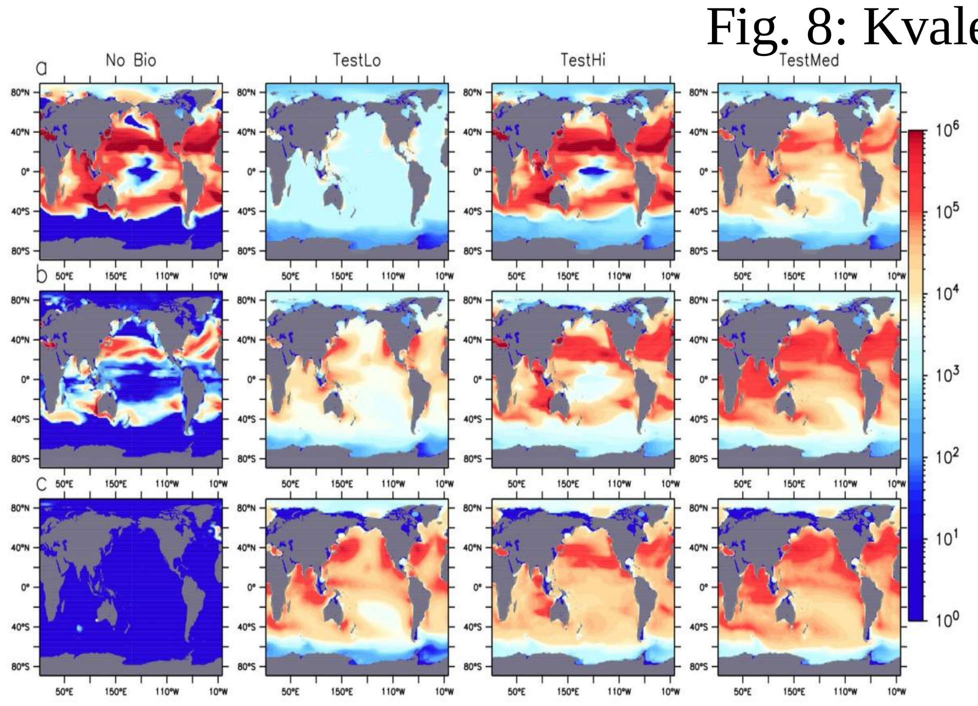
The "biological pump" can be one of the important drivers controlling the distribution of MP in the ocean.

Fig.6 : Fisher et al. (2022)



The vertical movement of particles is mainly affected by wind induced mixing within the mixed-layer and biofilm below the mixed layer.

Fig. 8: Kvale et al. (2020)



Total MP water column particle inventories (km^{-2}) in three depth brackets, at year 2020 in four models: No Bio–no biological uptake; TestLo –low surface MP conc. and efficient marine snow uptake of MP, while TestHi –a high MP particle load and large surface MP conc. TestMed –the moderate configuration, with a moderate MP inventory and moderate surface concentrations.

Selected References:

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