Is microplastic interfering with the marine carbon cycle? A modeling approach

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OCEAN SCIENCES MEETING 2022

Introduction

The **marine biological carbon pump** [1] is composed of several microbial pathways taking up atmospheric carbon that is transported to the deep geological carbon cycle.

This important mechanism is expected to be impacted by climate change [2], and **microplastic (MP) pollution** could further alter it [3].

Microbial organisms can colonize marine MPs (biofouling) and act as a ballast, causing MPs to sink. During sinking, the biofilm interacts with carbon content throughout the water column. This process could be a **novel pathway for biological carbon export** [4].

We present a simple model to **assess whether and where microplastic-mediated carbon export can occur in the Mediterranean Sea (MedSea)**.

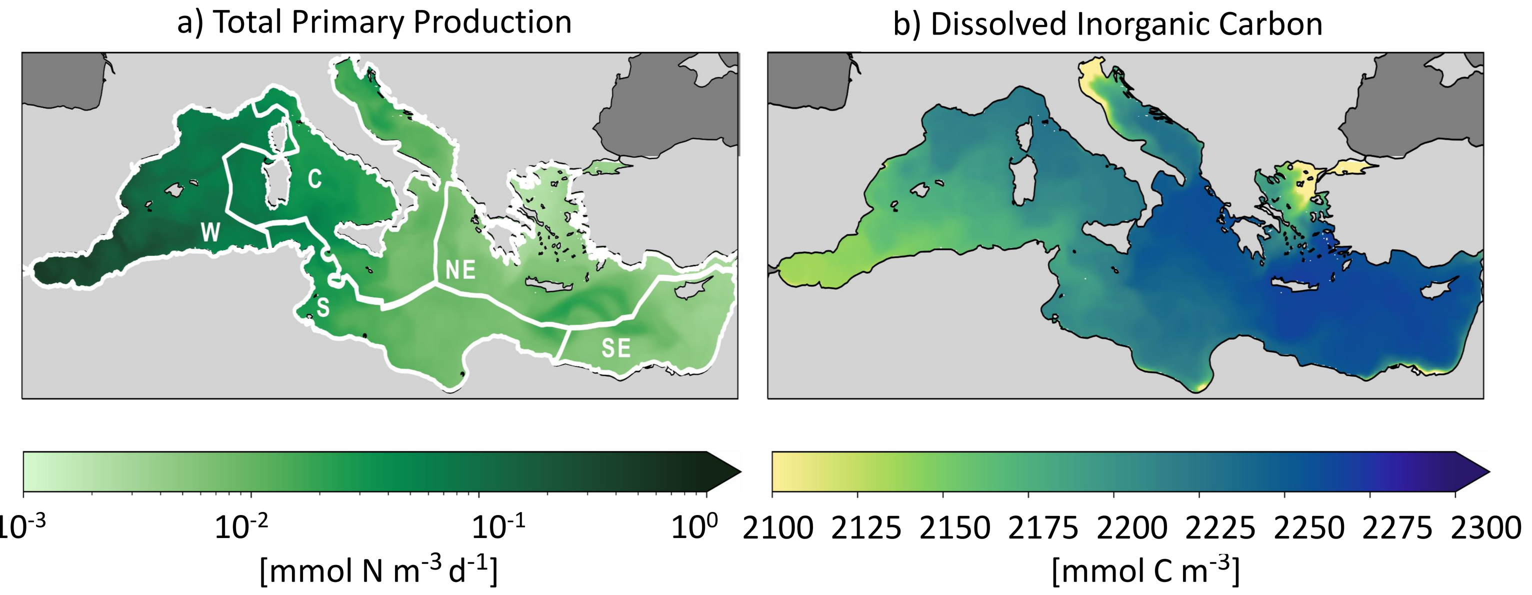

Figure 1. Time-averaged NEMO-MEDUSA data for the year 2004. a) Depth-integrated total primary production (TPP3); relevant spatial regions referenced in the analyses are highlighted: W – Western, C – Central, S – South, NE – North East, SE – South East. b) Surface dissolved inorganic carbon (DIC).

Methods

We combine the Parcels 2.3.0 Lagrangian particle-tracking framework [5] with the biofouling model proposed by [6] to simulate biofilm dynamics and resulting MPs' vertical motion. Physical and biogeochemical data are retrieved from the 5-day averaged NEMO-MEDUSA-2.0 ORCA00083-N06 outputs [7] (**Figure 1**).

The biofilm growing on particles is considered as a carbon pool. The processes driving biofilm dynamics are related to mass transfer of carbon between MP particles and the other carbon pools at particle depth, as described in **Figure 2**.

Our offline model updates the carbon pools in the water column without feeding back these changes to NEMO-MEDUSA. Therefore, to avoid inconsistencies, we constrain the length of each run to 5 days, the time resolution of the NEMO-MEDUSA data.

MPs are homogeneously released over the MedSea, and their interactions with carbon pools in seawater are simulated from December 2003 to November 2004. Particulate organic carbon (POC) is accounted for as carbon exported at depth whenever it is released from MPs at a depth exceeding 100 m.

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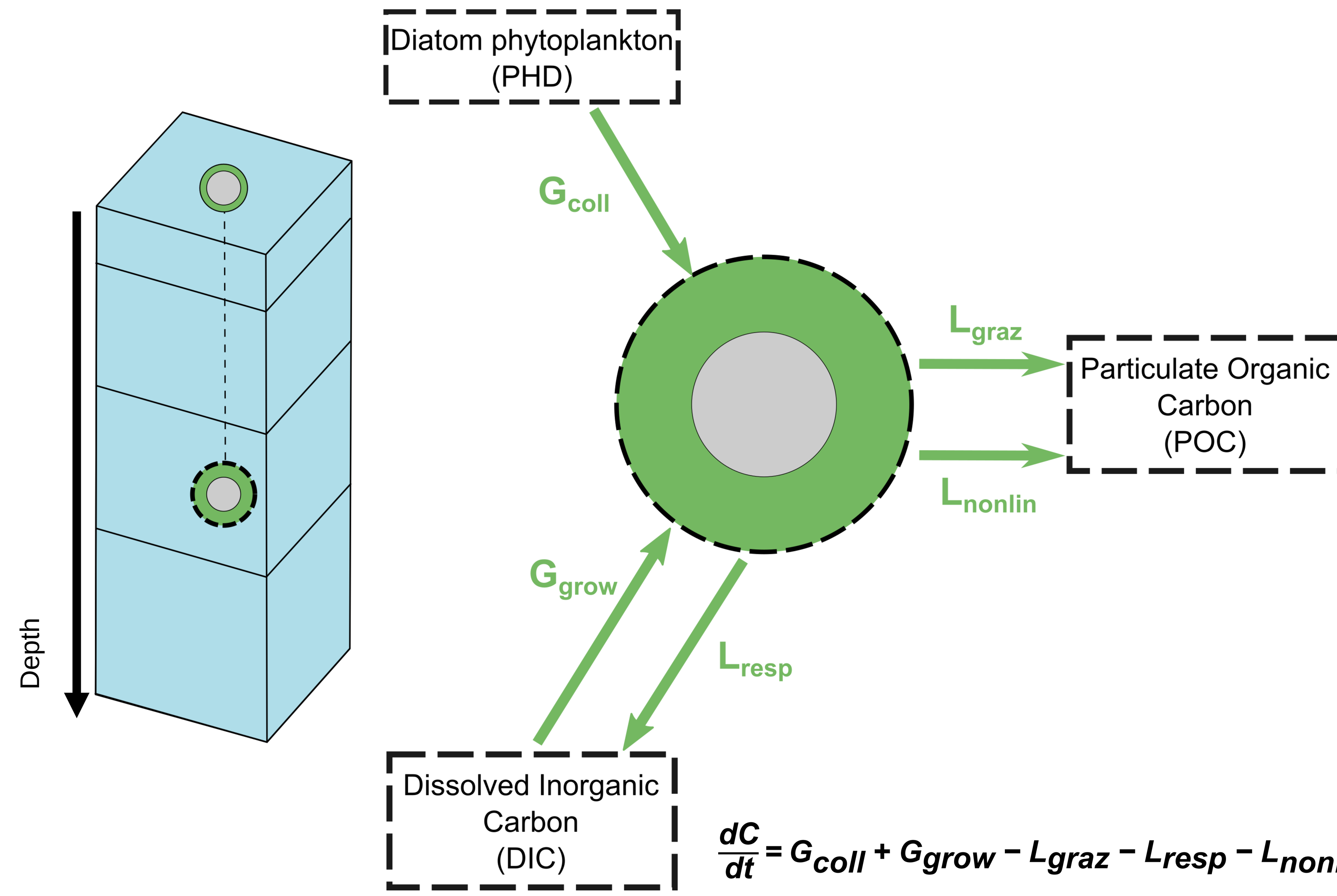
[7] Yool et al., (2013). *Geoscientific Model Development*, 6, 1767–1811
[8] Everaert et al., (2020). *Environmental Pollution*, 267, 115499
[9] Guyennon et al., (2015). *Biogeosciences*, 12, 7025–7046



$$\frac{dC}{dt} = G_{coll} + G_{grow} - L_{graz} - L_{resp} - L_{nonlin}$$

Figure 2. The MPs-seawater carbon exchanges in our model, as resulting from the equation above (from [6]). The grey circle is a MP particle; bold dashed lines contour the modeled carbon pools: free-floating diatoms (PHD), particulate organic carbon (POC), dissolved inorganic carbon (DIC), and particle-bound carbon. Green arrows represent the exchanges between the pools.

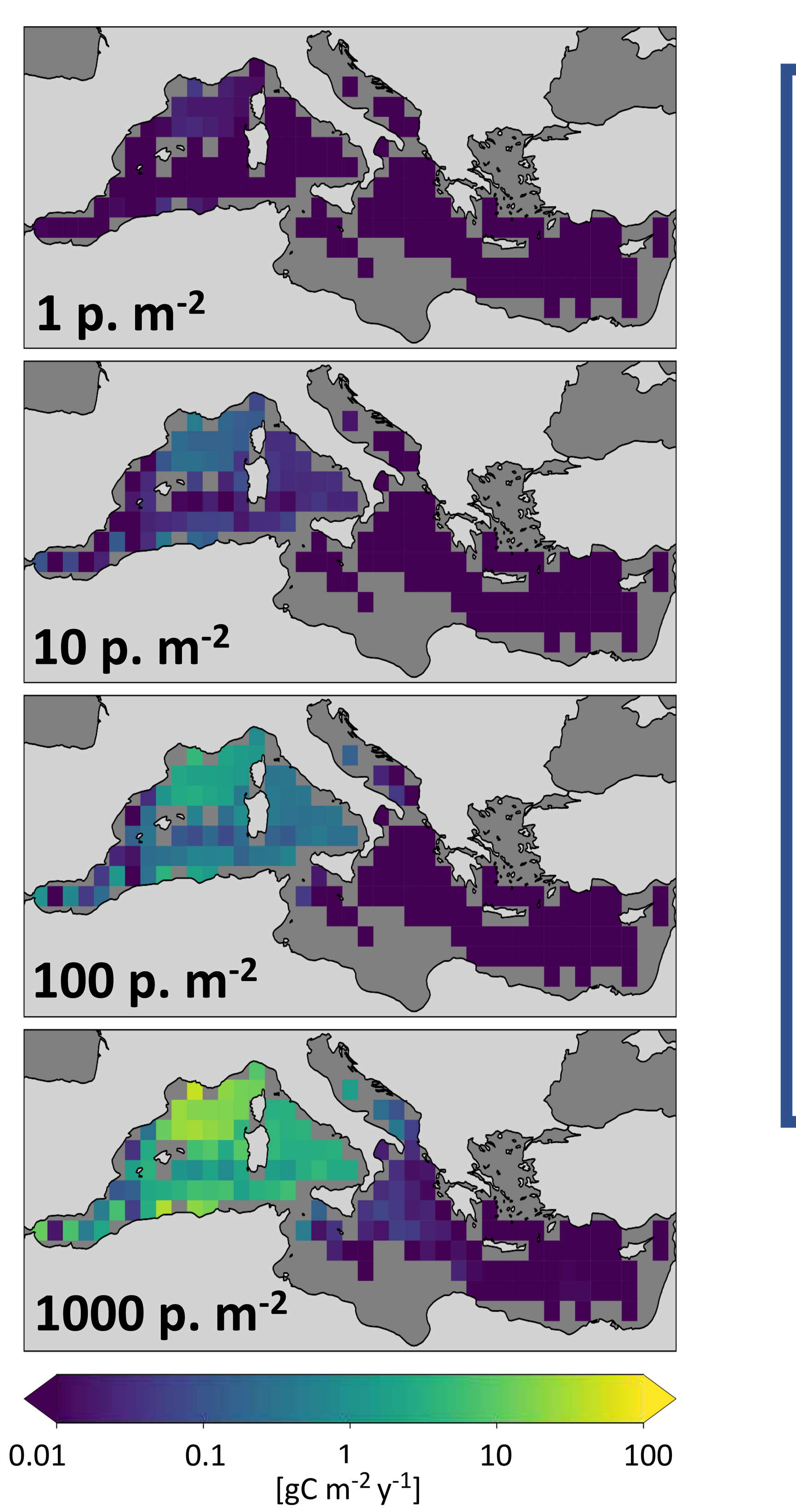


Figure 3. Estimates of yearly carbon export below 100 m (in gC m^{-2} y^{-1}) for the four particle concentrations tested (in particles m^{-2}). Grey areas within the MedSea have no carbon export.

Testing a set of concentrations

We simulated logarithmically-spaced concentrations of MPs from 1 to 1,000 particles m^{-2}.

MP concentrations seem correlated to the related carbon export: **higher MP concentrations lead to more carbon exported**.

MP-mediated carbon export is more intense in the **Western MedSea**, an area characterized by high TPP (see **Figure 1**), thus more favorable for biofilm growth, causing MPs to sink.

No export seems to occur in the Southern MedSea: MPs sinking there reach shallow depths, insufficient to contribute to carbon export.

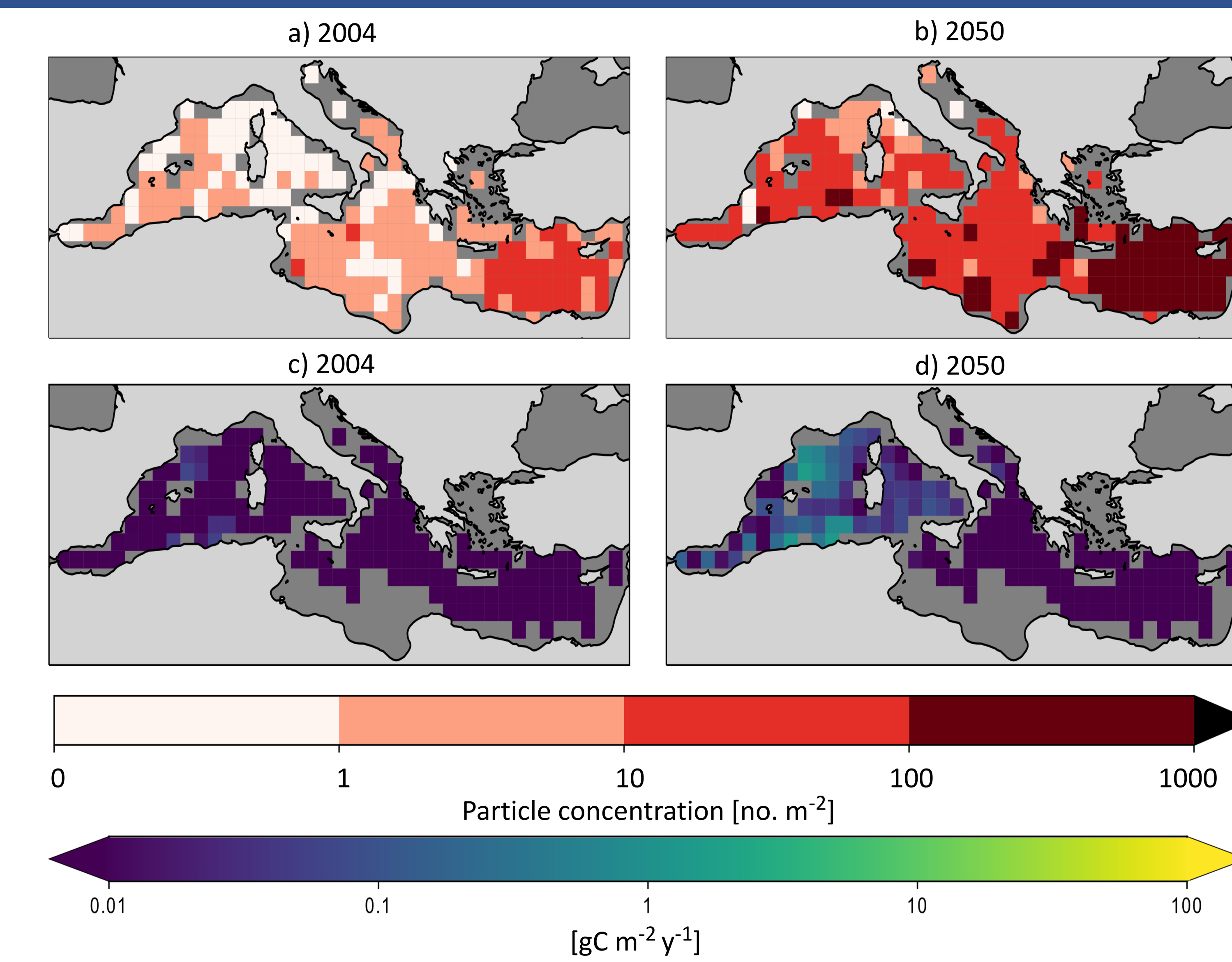


Figure 4. Upper plots: realistic MP concentrations in 2004 (a) and 2050 (b), from [8]. Lower plots: estimates of yearly carbon export (in gC m^{-2} y^{-1}) below 100 m related to MP concentrations in 2004 (c) and 2050 (d).

Simulating realistic MP concentrations

We then simulated two plausible scenarios of MP pollution in the MedSea for **2004** and **2050** respectively [8] (**Figure 4a** and **b**).

MP-mediated carbon export occurs only in few locations of the **Western region**, with **very low values** resulting from MP concentrations in 2004 (**Figure 4c**), showing an increase in 2050, following projected MP pollution (**Figure 4d**).

Despite the highest MP concentrations, the Eastern MedSea does not seem to contribute much to carbon export.

At **2050 MP concentrations**, MP-mediated carbon export could start representing a pathway for carbon export in the **Western** (**4.5% of total yearly carbon export** as estimated in [9]) and **Central** (**2.8%**) regions (**Figure 5**).

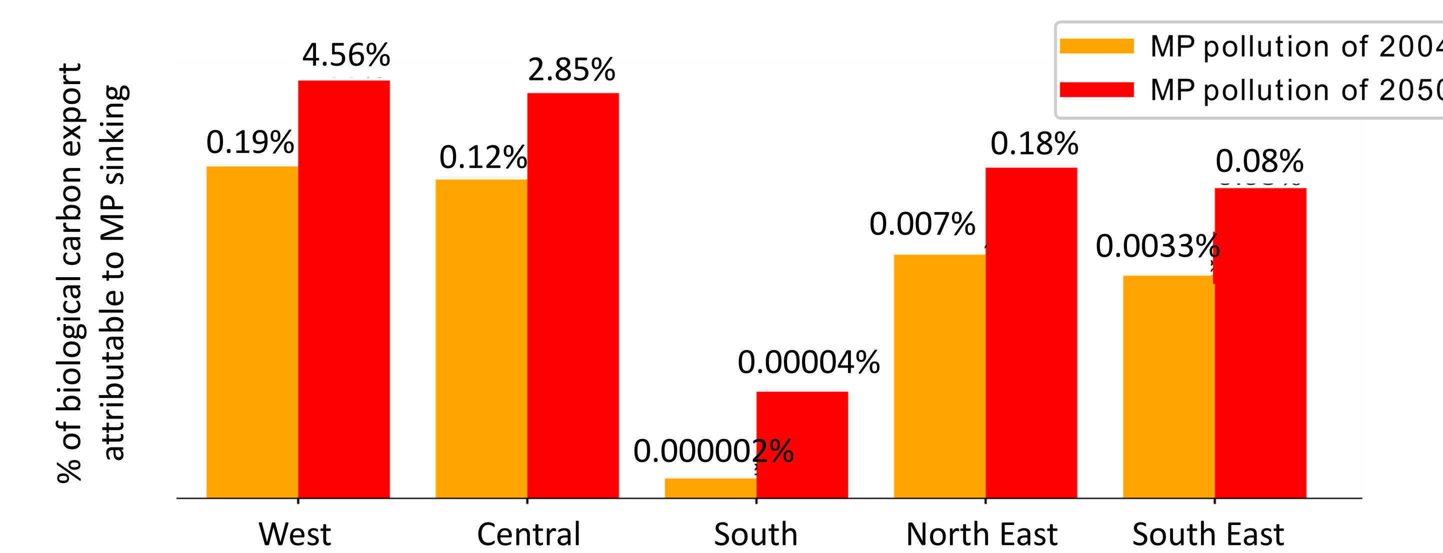


Figure 5. Fraction of the total yearly carbon export (from data by [9]) that can be attributed to MP particles in each of the five regions of the Mediterranean Sea identified in **Figure 2a**.

CONCLUSIONS

MP-mediated carbon export mainly occurs in the **Western MedSea**, yet with **minor contributions to total carbon export**.

As MP concentrations are expected to increase by 2050, so will the related carbon export, potentially exacerbating the effects of climate change on the MedSea's biological carbon pump.

Further modeling experiments, thoroughly accounting for the complexity of **MedSea biogeochemistry**, are crucial to advance the understanding of MP-mediated effects on the carbon uptake capability of the MedSea.