Binding approaches: Integrating experiments and models to decode marine gel production by coastal diatoms

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Marine gels are organic polymers spanning from dissolved Exopolymeric Substances (EPS; nm to µm) to Transparent Exopolymer Particles (TEP; µm to mm). They play a key role in marine ecosystems by enhancing flocculation between organic and mineral particles. This process significantly affects the size distribution, density and vertical transport of Suspended Particulate Matter (SPM) as well as the carbon cycle in the ocean. In turbid coastal zones, the TEP produced by phytoplankton determines the seasonality of the SPM concentration and influences the export of particulate organic matter. Although the biogeochemical importance of TEP and EPS is now recognized, the factors controlling their production by phytoplankton remain poorly understood and their dynamics is seldom included in biogeochemical models. This study combines experimental laboratory approaches with mechanistic numerical modeling in a turbid coastal zone to decipher the complex relationships between light intensity, interspecific variation, and marine gel production.

Laboratory experiments were conducted on six representative marine diatom strains isolated from the coastal waters of the Belgian Part of the North Sea. According to the carbon overflow hypothesis, excess in cellular internal carbon compared to nutrients can lead to the excretion of excessive carbon in the form of EPS which can subsequently aggregate to form TEP. To investigate the EPS and TEP production under varying environmental conditions, the strains were subjected to varying light intensities to examine their physiological responses. EPS and TEP concentrations were measured together with phytoplankton and bacterial abundances as well as particulate organic carbon and nitrogen concentrations during exponential and stationary growth phases. This set of experiments is used to further develop a zero-dimensional biogeochemical model designed to simulate dissolved organic matter production and TEP formation during a mesocosm diatom bloom.

Analysis of EPS production across strains revealed distinct patterns. The maximum specific EPS production rate varied by 35% across the six strains tested. No significant correlation between mean cell volume and specific EPS or TEP production was found. Across all strains, specific EPS and TEP production rates were positively related to light intensity: despite the absence of a systematic positive correlation, TEP formation was higher under high light conditions, in agreement with the carbon overflow hypothesis. Nevertheless, more detailed EPS and TEP production patterns displayed additional variability without apparent consistency, highlighting experimental limitations or knowledge gaps. Notably, the smallest taxon *Skeletonema sp*. exhibited irregular EPS dynamics with more important losses, potentially highlighting interspecific differences in reactivity of the produced EPS and of bacterial activity in the experiments. Cellular C:N ratios remained relatively stable, ranging from 5 to 7 mol C:mol N across all experimental conditions (no N limitation), suggesting maintenance of the internal stoichiometric ratios also in the stationary phase and showing no clear relationship with specific production rates of EPS or TEP.

Preliminary simulations resulted in an increased TEP:phytoplankton biomass ratio under high irradiance conditions compared to moderate and low light conditions, agreeing with the more similar and lower TEP production reached in medium and low light experiments. Yet, despite the low interspecific variation in maximum EPS production rates suggesting that a homogeneous parameterization could be used, other resource acquisition parameters (e.g., growth rate or nutrient acquisition parameters) are known to vary with cell size, and the current constant model parameterization could not allow the adequate simulation of all experiments.

This set of experimental data and simulations shows that the underlying mechanisms controlling marine gel production require further investigation and improvement of our biogeochemical models. Future work will focus on refining model formulation and parameterization using these experimental data to progressively fill the knowledge gaps in our understanding of these complex dynamics and enhance our ability to model particle and carbon dynamics as well as organic matter's fate in marine systems.

Keywords
EPS, TEP, Biogeochemical Model, Phytoplankton, Carbon Overflow, Carbon Cycle