Liège Colloquium

Phytoplankton and Microzooplankton responses to Calcium-based Ocean Alkalinity Enhancement during a Spring bloom in the North Sea

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Ocean Alkalinity Enhancement (OAE) is an emerging carbon dioxide removal strategy that leverages the natural dissolution of calcium- or silicate-based rock minerals in the ocean to increase seawater alkalinity, thereby enhancing CO_2 ingassing. However, its ecological implications remain uncertain, necessitating thorough assessment for safe and sustainable deployment.

To address this, we conducted a 39-day mesocosm experiment during the spring phytoplankton bloom of 2023 in the temperate, eutrophic waters off Helgoland in the North Sea. Six mesocosms (6 m^3 each) were used to establish an alkalinity gradient ranging from ΔTA 0 to 1250 µmol kg^{-1} in steps of 250 µmol kg^{-1}. OAE via hydrated lime addition ($Ca(OH)_2$) was simulated in a non-CO_2-equilibrated approach, which resulted in significant shifts in carbonate chemistry with, pCO_2 dropping from ~400 to < 50 µatm at ΔTA ≥ 750 µmol kg^{-1}, while pH increased from 8 to > 9. This setup allowed us to investigate how a blooming phytoplankton community responds to a gradient of OAE-induced carbonate chemistry changes, from mild to extreme.

The Microscopy and HPLC analysis revealed diatom-dominated phytoplankton community, with species composition varying across treatments. *Thalassiosira sp. and Coscinodiscus sp.* thrived under high pH (>8.8, ΔTA ≥ 750), while *Pseudo-nitzschia sp* dominated. across all other alkalinity treatments (ΔTA 0-1000), tolerating a wide range of pH from 8 to 9. *Coccolithophores sp.* abundance decreased from ΔTA250, while *Cryptophytes sp.* flourished under elevated alkalinity (ΔTA ≥ 1000 µmol kg^{-1}). Generally, we observed a delayed phytoplankton bloom development at higher TA treatments (ΔTA ≥ 1000 µmol kg^{-1}), while the two lowermost treatments exhibited an initial bloom followed up by a subdued secondary bloom. Microzooplankton composition shifted over time, from ciliate dominance early in the experiment to increased dinoflagellate prevalence across all treatments, reflecting changes in resource availability and trophic interactions rather than direct alkalinity effects.

Our findings underscore the sensitivity of North Sea spring bloom community to OAE and associated carbonate chemistry changes, highlighting the importance of understanding ecological responses to OAE. This research highlights the delicate balance between CO_2 removal objectives and ecosystem stability, emphasizing the need for further research to assess OAE impacts before large-scale OAE implementation.