Can a non-equilibrated Ocean Alkalinity Enhancement approach impact phytoplankton communities during bloom conditions? Insights from a Mesocosm Study.

Giulia Faucher[1], Leila Richards Kittu[1], Laura Marín-Samper[2], Svetlana Petric[1], Kai Schulz[3], Juliane K. Tammen, Ulf Riebesell[1]

1 GEOMAR Helmholtz-Centre for Ocean Research Kiel, Germany

2 Institute of Oceanography and Global Change, University of Las Palmas of Gran Canaria, Spain

3 Centre for Coastal Biogeochemistry, Southern Cross University, Australia

Enhancing ocean alkalinity (OAE) through the large-scale addition of calcium or silicate-based rock minerals to the surface ocean is a potential method for achieving negative CO_2 emissions and mitigating climate change. At present, the rapid development of technologies for OAE applications meets an urgent need to deepen our understanding of their potential ecological implications to ensure a comprehensive environmental impact assessment of this marine-based carbon dioxide removal technology.

For this purpose, we conducted a 39-day *in situ* mesocosm experiment assessing the response of a natural plankton community. The experiment took place in the temperate, eutrophic waters of the German North Sea near Helgoland, covering the spring phytoplankton bloom of 2023. Two total alkalinity (TA) gradients (up to ΔTA 1250 µmol L^{-1}, in increments of 250 µmol L^{-1}) were established, simulating non-CO_2-equilibrated hydrated lime alkalinisation through the addition of calcium chloride and sodium hydroxide. In one set of mesocosms, TA was added to the entire water column, while in the other, twice the alkalinity was added only to the upper half, creating two distinct layers, which were mixed two days later to simulate delayed dilution. These extreme carbonate chemistry manipulations (pH > 9) were intended to explore impacts across a wide range of ecosystem dynamics and, identify critical thresholds for OAE applications.

We report on the effects of OAE on phytoplankton bloom dynamics and community composition in the simulated OAE scenarios. The first results show that the maximum quantum efficiency of photosystem II (F_v/F_m), an indicator of phytoplankton photophysiological stress, declined immediately at alkalinity addition exceeding ΔTA of 750 µmol L^{-1}, indicating a short-term shock response. This decline reversed within a few days suggesting a recovery, potentially mediated by species-specific sensitivity to the carbonate system changes. Similar dynamics were observed in phytoplankton bloom development, where lower TA treatments exhibited earlier responses compared to higher TA treatments, as indicated by chlorophyll a, net community production, and gross community production rates. However, despite the initial delay, bloom development in high-TA treatments eventually recovered, suggesting a delayed but adaptive response to enhanced alkalinity. Changes in phytoplankton composition were also evident, with shifts in abundance and biomass of dominant taxonomic groups occurring at ΔTA > 500-750 µmol L^{-1} (pH ≥ 9.12) depending on the TA dilution approach. This indicates that a shift in the phytoplankton community composition and structure may have occurred in the long(er) term, particularly in the two highest ΔTA treatments.

These results represent a crucial step toward defining threshold levels of TA addition to minimise potential ecological disturbances and establish a safe operating framework for non-equilibrated OAE implementations.