Uses and impacts of alkalinity enhancement

Ocean alkalinity enhancement (OAE) is the addition of alkaline materials to the surface ocean to raise the alkalinity and pH seawater, which can lead to additional uptake of carbon dioxide. Alkalinity enhancement is also used for other purposes, particularly to treat drinking water and wastewater, counteract acid rain, and to improve yield in shellfish hatcheries.

River, pond and lake liming has been used successfully to combat the effects of acid rain and surface runoff since the 1980s.

LOC-NESS will use highly purified, laboratory-grade, liquid sodium hydroxide as the alkalinity source for this experiment. We chose this source because of its rapid dilution and traceability in the marine environment. Because of its purity, the effects of alkalinity enhancement can be directly assessed through our monitoring plan. The alkaline solution will rapidly mix with surrounding seawater, will not introduce any unwanted byproducts to the ocean, and does not bio-accumulate. While sodium hydroxide is the best material for the LOC-NESS field trials, we do not endorse its use for scaled or commercial OAE.

Figure 1: Alkalinity enhancement has long been used in shellfish aquaculture (inset, University of Maryland Center for Environmental Science) and in liming of rivers, lakes and ponds (main image, Kentucky Fish and Wildlife) to offset the effects of acid rain and runoff.

BIOLOGICAL IMPACTS OF OAE

The LOC-NESS alkalinity dispersal is designed to rapidly mix the added alkalinity with surrounding seawater in the wake of the dispersal ship. As the mixing occurs, models and laboratory tests indicate that the pH will drop quickly below 9 within 12 seconds, and the final pH of the patch will be approximately 8.4 once dispersal is complete.

Previous studies have documented the impacts of alkalinity enhancement and elevated pH levels on several phytoplankton groups, copepods (zooplankton), and several species of larval fish over a range of time scales from hours to months.

For example, one study (Faucher et al. 2024) found that when exposing marine organisms to sodium hydroxide, the effects of alkalinity enhancement were only observed at pH values higher than those proposed for the field study.

A study on adult and juvenile copepods (Camatti et al., 2024; below) found that negative impacts were seen for exposure of up to 48 hours to pH values much greater than those expected during the proposed field trial. There were no appreciable impacts caused by short-term exposure to moderate increases in pH (9 and 10). The exposure time of marine organisms to elevated pH during the field trials will be even shorter than the shortest time window studied during these experiments.

Another study (Goldenberg et al., 2024) of prolonged (months-long) impacts of exposure to pH 8.7 on Atlantic herring (*Clupea harengus*) and Atlantic cod (*Gadus morhua*) larvae showed a slight positive effect, suggesting that fish larvae of these important commercial species may be resilient to the long-term conditions that persist over large areas following initial OAE deployment.

Species studied and metric used	Lowest pH with an observed effect after 24h exposure
Diatom growth (*Phaeodactylum tricornutum*)	8.78
Copepod mortality (*Acartia tonsa*)	9.06
Oyster embryotoxicity (*Crassostrea gigas*)	8.88
Fish cell viability (*Sparius aurata*)	10.01
Patch pH after dispersal	8.4
Patch pH after 24 h	8.08

Table 1: The effects of high pH varied according to marine organism, but for all organisms, the lowest pH with an observed effect after 24 hours was higher than those expected soon after dispersal. (Faucher et al., 2024)

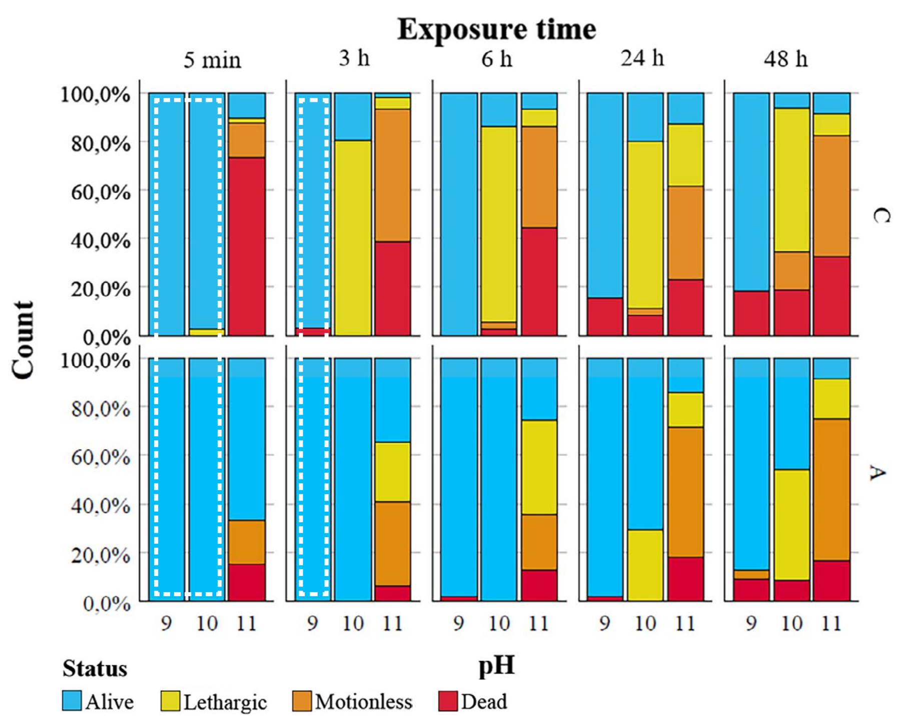

Figure 2: Copepodite (juvenile, top panels) and adult (bottom panels) copepod response to pH peak exposure. Reproduced from Camatti et al. 2024. The dashed-line boxes illustrate exposure conditions that are closest to those expected during the field trials.

REFERENCES

Camatti, E., Valsecchi, S., Caserini, S., Barbaccia, E., Santinelli, C., Basso, D. and Azzellino, A. (2024). Short-term impact assessment of ocean liming: A copepod exposure test. *Marine Pollution Bulletin* 198, 115833

Faucher, G. (2024). Ecotoxicology tests for OAE: a useful tool to indicate safe dosing thresholds. *Carbon to Sea Annual Convening 2024.*

Goldenberg, S. U., Riebesell, U., Brüggemann, D., Börner, G., Sswat, M., Folkvord, A., Couret, M., Spjelkavik, S., Sánchez, N., Jaspers, C. et al. (2024). Early life stages of fish under ocean alka linity enhancement in coastal plankton communities. *Biogeosciences* 21, 4521-4532.