APPENDIX F

Approaches to reduce CO_2 in seawater

The impacts of rising atmospheric CO_2 concentrations on seawater carbonate chemistry can be reduced using two possible approaches. The first is biologically-based, making use of the natural ability of the ocean's photosynthetic organisms (algae and plants) to capture CO_2. For example, seagrasses, kelps and other macrophytes remove CO_2 from seawater and convert it into living tissue. This CO_2 uptake can occur at sufficiently rapid rates to significantly improve water quality for organisms sensitive to carbon chemistry changes. Although a substantial fraction of this organic carbon is released as CO_2 when plant tissue decomposes, active photosynthesis may offer a means to locally reduce CO_2 in shallow coastal environments.

There has been considerable interest along the West Coast in protecting and restoring aquatic vegetation as a means to reduce CO_2 in coastal aquatic ecosystems. Seagrass beds and kelp forests are among the world's most productive habitats, with rates of net primary production that can exceed those of tropical forests. The ability of aquatic vegetation to influence coastal chemistry is evident from estuarine monitoring data that show day to night swings in pH whose magnitude can exceed near-term declines projected from OA.

The second approach uses abiotic methods to mitigate OA exposure. Abiotic methods can be used to increase chemical buffering capacity (alkalinity) of seawater or physically remove CO_2. Synthetic base chemicals or natural base minerals can be added to seawater to increase its alkalinity. This in turn neutralizes seawater acidity and buffers against the effects of increasing CO_2 on seawater chemistry. CO_2 can be directly removed from seawater using engineered approaches such as electrochemistry, electrodialysis, vacuum extraction, and aeration with a CO_2-depleted gas.

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There are potential co-benefits of habitat protection and restoration

While one potential benefit of protecting and enhancing aquatic vegetation is reducing CO_2 in seawater, additional co-benefits may also be realized. A portion of the CO_2 converted into vegetation can be buried in sediments. This process represents the potential long-term storage or sequestration of CO_2. On an areal basis, coastal vegetated habitats hold some of the highest concentration of organic carbon of any ecosystem on the planet, and serve as a globally important sink for carbon (i.e., blue carbon). Consequently, their conservation and restoration could one day become eligible for carbon offsets in carbon trading markets, such as the one established in California, or for other funding that promotes carbon sequestration. We also note the distinction between short-term removal of CO_2 and the long-term sequestration of CO_2 by vegetated habitats. For example, kelp forests, while highly productive and active in CO_2 removal on a daily and seasonal basis, grow on hard bottom habitats where local sediment burial and the potential for long-term carbon sequestration may be minimal. In contrast, emergent marsh vegetation uses CO_2 from the atmosphere for photosynthesis and releases CO_2 to surrounding waters through root respiration. Yet, these systems can be highly effective in trapping and sequestering carbon-rich sediments, or removing nutrients that may otherwise contribute to acidification or hypoxia in downstream habitats.

Another benefit of protecting and enhancing aquatic vegetation is the creation of habitat for fish and other biota. One of the Panel's **Actions** is considering the ability of aquatic vegetation to remove CO_2 from seawater in addition to its habitat value during habitat restoration planning. Accounting for both of these ecosystem benefits will assist in better achieving the full societal value of habitat restoration and management.

Advancing research to increase management options

Across the West Coast, researchers are actively investigating approaches for restoring aquatic vegetation, their role in locally modifying coastal seawater chemistry, and the daily to seasonal patterns of carbon uptake of these environments. In the K'ómoks Estuary on Eastern-central Vancouver Island, the transplanting of eelgrass from donor beds to previously disturbed estuaries has been successful in establishing new beds. Dive surveys have confirmed a transplant success rate of 95%. In Washington, pilot studies have reported elevated daytime pH in waters over seagrass beds relative to bare sediment habitats. In Oregon, oyster hatchery managers at Netarts Bay have begun to selectively draw seawater into the hatchery during hours when photosynthesis in the seagrass-rich system has reduced CO_2 to levels acceptable for their operations.

These examples highlight the potential applications of aquatic vegetation protection and restoration as actions to reduce CO_2 and ameliorate, if not offset, OA in local ecosystems. If successful, such actions can increase the range of options available to managers to address OA. Important questions nonetheless remain as to the effectiveness of aquatic vegetation CO_2 reduction as an OA mitigation strategy and must be answered before implementation. For example: Will the benefits of photosynthesis be offset by increases in the daily and seasonal swings in carbon chemistry? How far does the spatial "footprint" of such effects extend? What are the range of settings and locations where vegetation protection and restoration will be most successful and beneficial? Can such measures be employed in concert with other management actions to maximize conservation benefits? These questions can be addressed directly in larger-scale, proof-of-concept demonstration studies. When conducted across a range of habitats, these efforts can provide managers with new, useable knowledge of if and where protection and restoration of vegetated habitats will sufficiently remove CO_2 to meaningfully mitigate OA.

Options from engineering approaches

Human intervention to mitigate OA through engineering addition of basic materials and removal of aqueous CO_2 is still in early development. The effective scale, ecological consequences, and carbon footprint of such efforts remain uncertain but can offer important options for impacted industries. For example, shellfish growers on the West Coast have begun to use alkalinity management to offset the increase in carbonate mineral corrosivity from OA in hatchery settings. Although currently available approaches remain likely tractable only at localized scales and in controlled environments, future technological advances may broaden the applications of engineering approaches. Further research will be needed to determine the safety, cost effectiveness and potential scale of such efforts in countering the ongoing global progression of OA and its regional expression on vulnerable West Coast ecosystems.

This report was produced by the West Coast Ocean Acidification and Hypoxia Science Panel (the Panel), working in partnership with the California Ocean Science Trust. The Panel was convened by the Ocean Science Trust at the request of the California Ocean Protection Council in 2013, working in collaboration with ocean management counterparts in Oregon, Washington, and British Columbia. Ocean Science Trust and the Oregon Institute for Natural Resources served as the link between the Panel and government decision-makers. The information provided reflects the best scientific thinking of the Panel. More information on the Panel can be found at www.westcoastOAH.org. Cover image: Eric Heupel / Creative Commons License; circle inset (sea palms): Tess Freidenburg.