

Short Communication

Bivalve Farming Is Not a Solution for Marine Carbon Dioxide Removal

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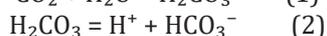
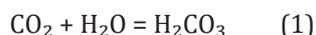
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Marine carbon dioxide removal (mCDR) refers to a suite of approaches that artificially enhance the ocean's capacity to remove carbon dioxide from the atmosphere and store it for long periods. Interest in mCDR has grown because most climate pathways consistent with limiting global warming to 1.5–2 °C require not only rapid emissions reductions but also substantial “negative emissions” during this century. The ocean is considered a potentially large CO₂ sink and has already absorbed roughly one quarter of excess atmospheric CO₂ [1,2]. mCDR approaches can be broadly grouped into five categories: ocean alkalinity enhancement, direct ocean capture via chemical or electrochemical processes, seaweed or phytoplankton cultivation, artificial upwelling/downwelling, and the protection and restoration of blue-carbon ecosystems such as mangroves, seagrasses, and salt marshes. Recently, bivalve farming has been proposed as a potential mCDR strategy. In 2022, 18.7 million tons of marine mollusks, predominantly bivalves, were produced worldwide [3]. Because a substantial amount of carbon is sequestered in their shells, bivalve farming has been suggested as a potential mCDR hotspot for climate change mitigation, and the possibility of claiming carbon credits has also been investigated [3–7]. It is important, however, to emphasize that the objective of mCDR is to remove CO₂, not merely carbon.

The seawater CO₂ system and the formation of bivalve shells are governed by thermodynamics:



Equation (1) is governed by the solubility of CO₂. Equation (2) has a pK of about 6, and Equation (3) has a pK of about 9 in seawater, which has a pH of approximately 8. Equations (2) and (3) indicate that, in seawater, HCO₃⁻ is about 100 times more abundant than H₂CO₃ or dissolved CO₂ and about ten times more abundant than CO₃²⁻. Shell formation draws carbon from the most abundant carbon species, HCO₃⁻, and converts it into the least abundant form, CO₂. Indeed, Equation (4) shows that for every carbon atom sequestered in shells, one molecule of CO₂ is released into surface seawater and eventually into the atmosphere. In summary, shell formation stores one carbon atom but releases one CO₂ molecule, which contributes to global warming and is precisely the focus of mCDR.

Shellfish farming is, of course, more complex than simple thermodynamics. One additional process is the formation of soft tissue, which is traditionally the primary objective of farming. The flesh, or organic carbon, does take up carbon and thereby reduces CO₂ concentrations in seawater. However, it is well established that shells contain more carbon than the soft tissue; thus, mollusk growth results in a net release of CO₂. The controversy over whether shellfish farming absorbs or releases CO₂ arises from the claim that, when considering the ecosystem as a whole, it may nevertheless absorb CO₂. This argument is based on the growth of phytoplankton within shellfish farms, where photosynthesis consumes CO₂. If phytoplankton production is sufficiently high, photosynthetic CO₂ uptake could exceed CO₂ release from shell formation. Under such conditions, assuming adequate nutrient supply, shellfish farms could function as carbon sinks. However, this scenario effectively represents phytoplankton farming rather than shellfish farming. A recent mesocosm study [7] further suggests that oyster farming produces dissolved and particulate organic carbon and promotes organic carbon deposition in sediments. As a result, oyster-driven organic carbon production was reported to sequester more carbon than is released during shell formation, thereby enhancing atmospheric CO₂ uptake. Nevertheless, this study cannot be regarded as conclusive because it was conducted in a mesocosm and over a relatively short duration.

Most freshly produced dissolved organic carbon is labile and decomposes rapidly. For example, in the East China Sea, approximately 85% of primary production is regenerated within the seawater residence time of less than two years [8]. Consequently, only about 15% of biologically produced organic carbon, dissolved or particulate, survives and is exported to the Pacific Ocean. In the open ocean, organic carbon is rapidly remineralized within the euphotic zone, and only recalcitrant dissolved organic carbon enters the deep-water circulation, where it is isolated from the atmosphere for millennia [9]. Returning to the mesocosm study [7], even if oyster-driven organic carbon production temporarily exceeds carbon release from shell formation, most of the organic carbon would likely be remineralized to CO₂ after the short experimental period. Likewise, organic carbon deposited in mesocosm sediments would probably be regenerated into CO₂, or even more potent greenhouse gases such as CH₄ and N₂O, had the experiment been extended. Because mesocosm experiments are inherently limited in duration, the ultimate test of whether shellfish farming represents a credible mCDR strategy must rely on field observations. A recent synthesis [10] examined 48 studies on bivalve farming, of which only eight were based on observational

data. Seven of these eight studies reported net CO₂ release from the system. Notably, the most recent publication [11], which included the corresponding author of the mesocosm study [7], also documented intense CO₂ outgassing in an intensive mariculture bay, results that stand in direct contrast to those of the mesocosm experiment. In conclusion, shellfish farming is not a solution for marine carbon dioxide removal.

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Conflict of Interest

The author declares no conflict of interest.

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