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Opinion

Can Seaweed Cultivation Provide a CO_2 Sequestration Service that will Lessen Global Warming?

Álvaro Israel*

Israel Oceanographic & Limnological Research, The National Institute of Oceanography, Tel Shikmona, Haifa, Israel

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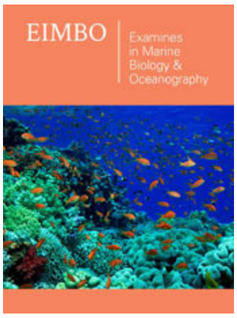

***Corresponding author:** Álvaro Israel, Israel Oceanographic & Limnological Research, The National Institute of Oceanography, Tel Shikmona, Haifa, Israel

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Opinion

Since the outburst of the Industrial Revolution, just about 270 years ago, the CO_2 concentration in the atmosphere raised by 48% (NASA 2024, https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121, accessed May 2024). In contrast, towards the end of the Ice Age similar changes in CO_2 took approximately 10,000 years to occur! As a result, and together with other so-called anthropogenic greenhouse gases, CO_2 has warmed the atmosphere, ocean, and land by accumulating additional energy (i.e., heating) in the Earth's climate system. Reduced food and water security, increased extreme weather events, irreversible losses of terrestrial and marine ecosystems are some of the consequences of climate change [1]. The net-zero target commitment under the Paris Agreement established that Carbon Dioxide Removal (CDR) from the atmosphere through developing technologies is crucial to curb the rise in global temperatures.

Exploiting marine macroalgae (seaweeds, both in nature and cultivated) as a vehicle to reduce global carbon has been repetitively underlined in dozens of scientific publications released only in the last five years. Much of these reports are theoretically-driven arguments and a variety of modelling tactics to highlight the seaweed potential as effective carbon scavengers [2-5], with solid experimental data supporting these claims still at large. Seaweeds are outstanding photosynthetic organism owing their unique photosynthetic traits [6], which combined with efficient nitrogen and phosphorous uptake rates translate into remarkable Net Primary Productivity (NPP). Seaweeds form the largest and most productive underwater vegetated habitat on Earth, drawing a flux of CO_2 comparable to the Amazon rainforest every year. High commodity production of seaweeds can also deliver important additional benefits and ecosystem services, therefore giving extra support to human needs. Still, whether seaweeds can trap CO_2 for required long periods (100 years and more) and by so doing be effective in climate regulation is highly controversial (Figure 1).

Following photosynthesis, seaweed biomass from natural populations and extensive farming can be harvest for direct consumption, thus adding to C sequestration. Also, release of Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) occurs abundant and back into seawater; returning to air. Some DOC (carbohydrate exudates and recalcitrant carbon) and POC may enter long-term storage as carbon sink and carbon trapped in sediments. Microbial activity plays a major role in all steps of carbon paths from air to deep sea, and vice-versa.

Seaweed farming is widely promoted as an approach to mitigating climate change despite limited data on carbon removal pathways, and uncertainty around benefits and risks at operational scales [3-5,7-9]. Large seaweed cultivation may affect the environment, with NPP varying across taxa, space and time [10,11]. Indeed, there are some negatives components involved in extensive seaweed cultivation particularly in coastal ecosystems and they may include:

a) **Biodiversity impacts:** seaweed farms may alter pH, sediment composition, organic content, and water flow with variable effects on local flora and fauna

b) **Light penetration:** at large scales, seaweed farming can reduce light penetration and therefore primary productivity in the water column. This can be of particular concern in shallow waters

c) **Nutrient budget:** seaweed farms absorb nutrients like nitrogen and phosphorus, which provides some environmental benefits but risks depleting nutrients below levels required to sustain natural marine productivity if expanded substantially

d) **Effects on carbon budget:** extensive seaweed cultivation on CO_2 capture might be minimal in freely moving open water bodies, yet substantial quantities of photosynthetic products released could potentially raise regional pH levels. Further, the specific effects of cultivation on carbon cycling remain uncertain, necessitating further investigation

e) **Flow dynamics:** seaweed cultivation systems significantly impact seawater flow and nutrient dynamics in marine ecosystems. Careful consideration of seaweed farm locations is crucial to maintain ecosystem resilience and expansion necessitates thoughtful planning and management strategies to mitigate potential ecological disruptions and maintain the health of marine ecosystems. Developers must consider appropriate scales and sites to balance production and sustainability through monitoring, research, and mitigation measures [10].

While the impact of these changes might be negligible in small to medium farming initiatives, the potential ecological repercussions of large-scale ventures remain uncertain [12,13]. The quantity and fate of Dissolved Organic Matter (DOM) and Particulate Organic Matter (POM), both common carbon-rich fractions from seaweed cultivation, their transportation, and their implications on marine habitats, including sediment oxygenation, hypoxia, and nutrient fluxes, necessitate further detailed investigation (Figure 1). To mitigate these impacts, comprehensive studies are needed to determine the precise volumes and environmental factors governing the release of DOM and POM [14,15]. Understanding the potential ecological consequences, especially in depositional zones, would aid in the development of effective management strategies for large-scale seaweed farming initiatives.

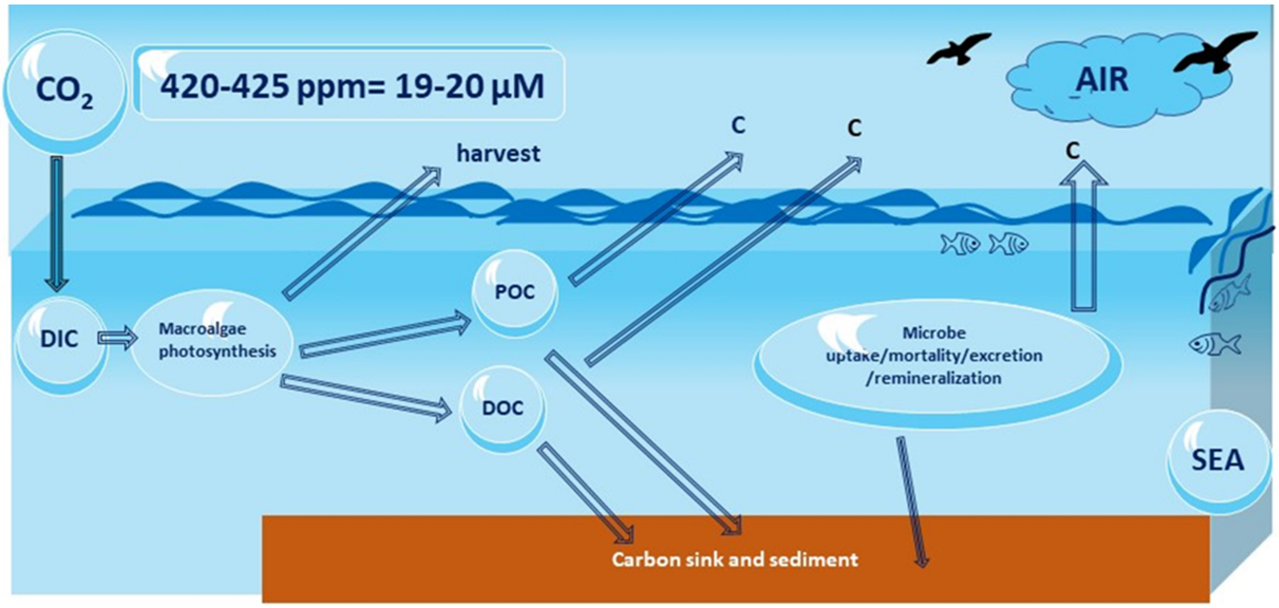

Figure 1: Moving carbon from the atmosphere to the deep sea and sediments via seaweed photosynthesis (Biological Carbon Pump).

Under current global climate policies, by the year 2100 the seaweed aquaculture sector will need to produce annually about 100 billion tonnes of seaweed biomass to effectively offset the emissions derived, for example, from the agricultural sector (comprising today roughly 12% of total Carbon emissions). Under current production rates, the global seaweed industry will produce only about 12 billion tonnes. This approximate one order of magnitude gap is extremely challenging. Large seaweed cultivation and sustainable technologies are in their infancy. Hence, clearly technical, biological and economic assessments and gaps need to be resolved before an effective and sustainable, seaweed-based mass production intended for the sequestration of CO_2 is established [13-17].

From the above arguments one can conclude that

a) For valid estimates of seaweed C-sequestration, the carbon flow and faith after CO_2 capture require evaluation from a wide interdisciplinary perspective

b) At present, large-scale global carbon mitigation through seaweed photosynthesis is unlikely but local to regional applications appear more feasible

c) Large economic and technical uncertainties need to be address.

However, even if the above burdens are satisfactorily overcome, "the research community must guard against the hyperbole that is beginning to permeate the conversation, such as that which beset the microalgae biofuel movement" [3], initiated in the 1970's and continued until the early 2000's. While cultivation of seaweeds only will likely not solve the problem of climate change, indirect valuable benefits must be considered. Nonetheless, more scientific work and technological developments in seaweed aquaculture are needed to make this happen.

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