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FORMAL COMMENT

Seaweeds for carbon dioxide removal (CDR)–Getting the science right

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To keep global warming < 2˚C, Almaraz et al. [1] highlight the need to drastically reduce greenhouse gas emissions from food production and remove atmospheric carbon dioxide by 2050. They provided an expert analysis of the potential of terrestrial based biological methods of carbon dioxide removal (CDR), including technologies that "demonstrated high impact potential supported by peer-reviewed literature". However, scientific rigour was not applied to their brief consideration of marine CDR strategies, specifically ocean afforestation which is the deliberate expansion of seaweed (macroalgal) aquaculture into the open ocean where they do not naturally grow, and the cultivated biomass sunk to the deep ocean for CDR. Ocean afforestation (OAf) is subject of intense debate [2–5] and peer-reviewed literature questioning its application for CDR were available before Almaraz et al. submission. Here we highlight some key points missed by Almaraz et al. to be considered prior to investments in large scale OAf.

1. All CDR methods will be required to undergo Monitoring, Reporting and Verification (MRV) to ensure that CO_2 removed from the atmosphere is securely stored and does not return to the atmosphere in the near future [6]. For marine systems, MRV is particularly difficult because of the complexity of measuring air-sea CO_2 equilibration [7–9]. Any seaweeds reaching the deep ocean may form a carbon storage pool but this is not directly linked to CDR. This is because in the open ocean, it takes on average 1 year for CO_2 to enter seawater and replace the CO_2 removed via seaweed photosynthesis; e.g. for open ocean *Sargassum* spp. populations, when air-sea CO_2 equilibration is accounted for, CDR is just 6–33% of the maximal potential [10]. This is explained by the water body from which Sargassum removed CO2 being subducted under another water body before full equilibrium is reached [9, 10].
2. Estimates of the oceanic regions where seaweeds could be cultivated are based on inorganic nitrogen (nitrate) inventories [2, 3, 11]. Productivity of 30% of the global ocean is iron limited preventing healthy seaweed growth [12].
3. There are potential side effects that may result from an 'ecological invasion' of the open ocean by large scale seaweed farms in which highly diverse native phytoplanktonic communities are replaced by mono-cultured seaweeds [3, 13]: among them, nutrient re-allocation from phytoplankton to seaweeds; allelopathy, which will likely alter oceanic food webs; and release of climate reactive volatile organic compounds which may affect cloud dynamics and solar radiation [13].

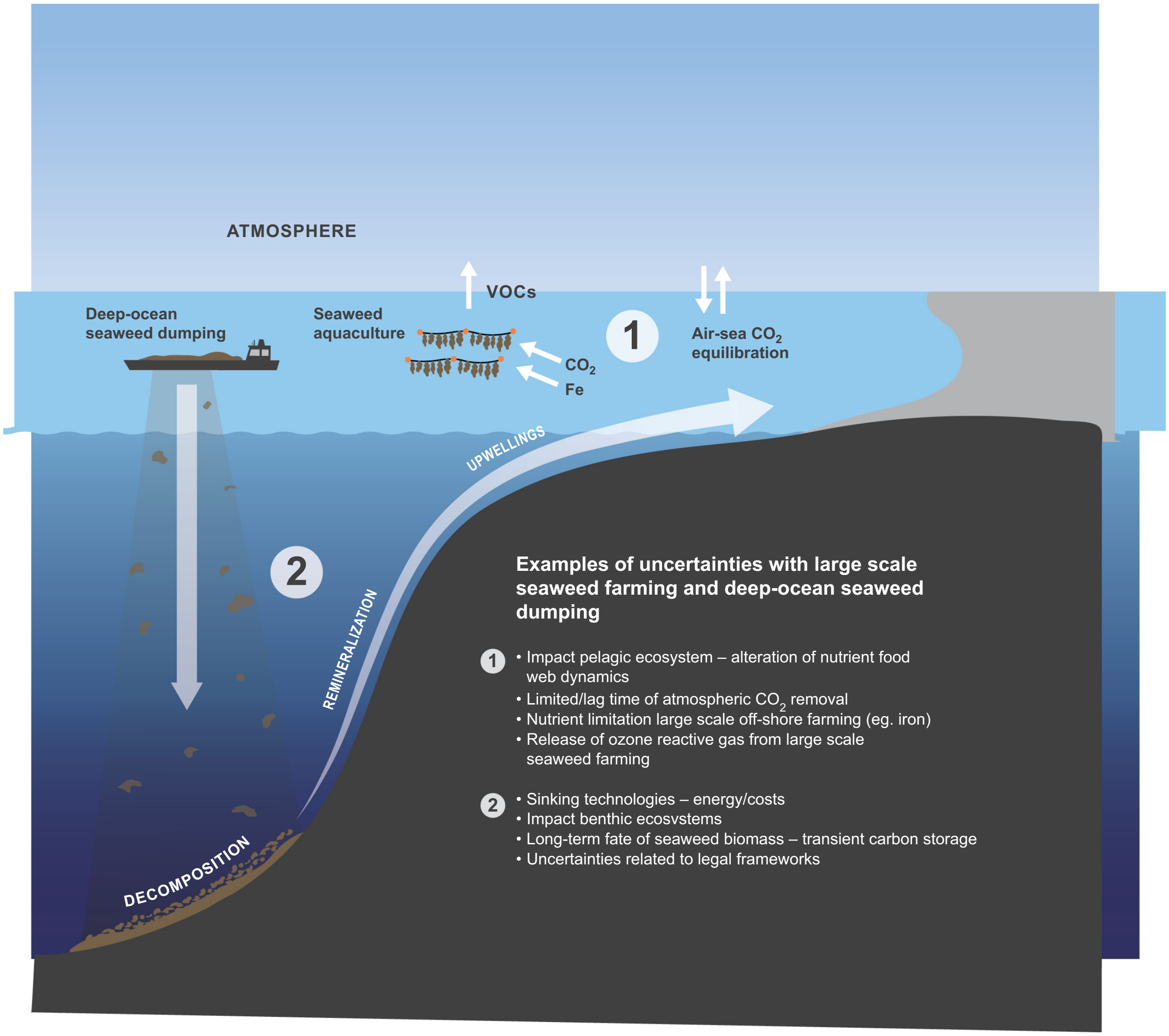

Fig 1. Examples of uncertainties with 1) large scale seaweed farming and 2) deep-ocean seaweed dumping (from references used in the text).

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4. The fate of seaweed biomass accumulating on the deep-ocean floor is uncertain. It risks impacting negatively deep sea ecosystems [14] and seaweed biomass not making it to the ocean floor will undergo elemental recycling and transformation to CO_2. Time scales for carbon decomposition and remineralization, as well as movement of seaweed biomass, are unknown, risking only transient carbon "sequestration" and not CDR on a climate-relevant time scale [15]. Fig 1 illustrates key uncertainties associated with large scale seaweed farming and deep-ocean seaweed sinking.

Studies like Almaraz et al. [1] are important for navigating the portfolio of CDR solutions; however, any inclusion needs to be supported by rigorous evaluation of net storage capacity (i.e. MRV) as well as feasibility (costs, infrastructure, environmental impacts, societal issues, etc.) to assess the true CDR potential. The risk may otherwise be development of misguided policies.

Author Contributions

Conceptualization: Max Troell.

Project administration: Max Troell.

Writing – original draft: Max Troell.

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