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Mini-Review

A Shellfish Manifesto for Sequestering Atmospheric Carbon in Quantity

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Mini-Review

Atmospheric CO₂ is sequestered within shellfish shells as an indigestible, crystalline and chemically stable mix of calcium and calcium-magnesium carbonates; when the animal dies the shell remains for geological periods of time. Effectively, the CO₂ is permanently removed from the atmosphere. That's the animal's generous legacy and our inheritance. It is the certainty and permanence of the removal of CO₂ from the atmosphere that makes biotechnology using calcifying organisms so attractive as a means to ameliorate climate change. The shellfish cultivation industry is the only industry on the planet that can expand without damaging the atmosphere, we want shellfish producers to greatly expand their production specifically to generate more shell. The crucial first step is to reverse, with absolute scientific and logical confidence, today's general acceptance of the misconception that "calcification releases CO₂ into the atmosphere". This stridently maintained, but mistaken, interpretation ignores biological chemistry (which is controlled by the organism) in favour of open water chemistry (which is imposed on the organism) and directs humanity's attention away from the only ecosystem on this planet that possesses the physiological capability to remove permanently the excess CO₂ from our atmosphere. Anyone who has ever enjoyed a meal of shellfish knows from personal experience that, at the conclusion of the meal, diners are left with a bowl of discarded shells.

Consequently, it doesn't matter which version of the marine chemistry mantra you believe ("calcification is /OR/ is not a CO₂-releasing process"), it doesn't matter that the shellfish spend their lives "exhaling" respiratory CO₂ (we all do that!), it doesn't matter that the boats burn diesel fuel to CO₂ day in-day out, or that shore facilities are not carbon neutral (most, if not all, currently-operating marine facilities are like that). It doesn't matter because the fact is that our consumption of every ton of freshly harvested shellfish leaves behind (on average) half a ton of freshly precipitated limestone in the shells. Most importantly, the shell material is 95% inorganic calcium carbonate which remains sequestered for millions of years (unless someone treats the shells as "food waste" fit only for incineration). There are two other steps we must take. CHANGE the present-day paradigm of aquaculture, which is to cultivate shellfish for food, to cultivating shellfish for their shells (treating the food as a by-product). This change of paradigm places the value of the cultivation exercise on the production of shell and its removal of carbon from the atmosphere. This allows us to take the monetary value of the food that results as a by-product, so that, effectively, the food value is the earned interest on the capital invested in the shell-cultivation exercise.

AN ABSOLUTE ESSENTIAL is that production of shell by this New Generation Shellfish Farming (by present-day Old Generation Shellfish Farming too, for that matter) is INCLUDED in CARBON-OFFSETTING PROGRAMS. Those used by the general public to offset the carbon emissions of their transport and other domestic activities, are likely to be attracted by projects to fund shellfish cultivation because for anyone who has enjoyed a shellfish meal it will be self-evident that a lot of shell is left over after the meal. Advertising [*'Eat more shellfish. SAVE the atmosphere'*] can educate consumers in just a few words of the shells' ability to offer a permanent removal of atmospheric carbon. There is a wide variety of potential projects, ranging from support for developing/expanding local subsistence fisheries in the third world as a means to employ and feed communities in need, through to supplementing the funding of local (to the offsetting customer) aquaculture programmes to enable them to expand their conservation/restoration activities continually for several to many years. Primary CO₂ emitter industries might be encouraged to sponsor a different kind of help to balance their carbon footprints by funding the larger scale infrastructural activities which are anticipated, which include industrial scale installations offshore and ocean-going factory ships. The high-energy industries that most need to compensate their heavy carbon footprints have all the necessary skills and experience to take such large-scale efforts forward. Central governments should be persuaded and encouraged to fund shellfish cultivation to sequester atmospheric carbon as a contribution to their carbon neutrality goals. As well as making significant financial input to the projects most appropriate to them, their responsibilities could include political, legal and administrative facilitation of the anticipated projects [1-4].

Central funding and management (a development foundation?) should be available to invest cash immediately in every existing aquaculture enterprise with the aim of doubling their production each season for the next five to ten seasons, with central funding guaranteeing farm gate prices as the markets react and adapt to successively greater production volumes. This New Generation Shellfish Farming is aimed at whole-planet ecosystem repair and restoration. Take the food represented by shellfish meat as a by-product from the production of shell and leave or return the shell to the seabed from which it was harvested. Bivalve molluscs have been described as ecosystem engineers because the shells of earlier generations create their own reef habitats, which are of such significant size that they become important to general marine biodiversity. By providing habitats at different depths, they support and enhance entire ecosystems. Another positive characteristic of shellfish farming is that it presents no conflict between using land to grow food crops and using land to grow trees, or, for that matter, using land for pasture animals. There is no need for irrigation, food or fertilizer (Figure 1). Farming shellfish can be combined with restoration and conservation of overfished finfish-fisheries and usually involves so little intervention (beyond provision of habitats and, where necessary, protection of larvae and juveniles from predation (in 'nurseries') that there is no inevitable conflict with other activities. If we do amplify farming and harvesting greatly, we will start to produce shellfish meat *in excess of that required for the 'shellfish-as-a-delicacy' fine dining market*. Then we could start thinking about processed shellfish meat as an alternative to meat products produced from terrestrial farm-reared animals, in the expectation that reduced husbandry of farm animals for meat-eaters will release pastures for afforestation and reduce further destruction of existing natural forests. Pseudo-beef-burgers

made from shellfish meat are likely to be more readily acceptable than those made from the insects or cultured animal cells that some food technologists are keen to promote.



Figure 1: A Shellfish Manifesto for Sequestering Atmospheric Carbon in Quantity

About 70% of the Earth's surface is covered by water. We might as well use it sustainably to rescue our atmosphere, our planet and ourselves. I understand that the human population is projected to reach 10 billion by 2050. We already know that there isn't enough terrestrial farmland on Earth to provide even the present-day population with the affluent "western" diet. Let's not agonise about the present and growing food deficit, let's DO SOMETHING about it AND in a way that helps the atmosphere. As I write this, we have 28 years to ramp up aquaculture to a level where, say, the UN could agree in 2050 "to ensure that the means exist to provide every individual human on the planet with one meal of shellfish meat every day."

For the sake of easy arithmetic, let's assume that this meal is comprised of 100 g of fresh or processed shellfish meat. Fulfilling the promise of this policy in 2050 means producing EACH DAY:

$$10 \text{ billion} \times 0.1 \text{ kg} = 1 \text{ million tons (metric) of shellfish meat.}$$

We know that, as a minimum average guesstimate, 1 million tons of shellfish meat will have been enclosed within at least 1 million tons of shell, and that the shell is 95% CaCO_3 , and CO_2 represents 44% of the molar mass of calcium carbonate;

Consequently, 1 million tons of shell = $1 \text{ million} \times 0.95 \times 0.44 = 418,000$ tons of atmospheric CO_2 removed permanently from the atmosphere EVERY DAY.

This is about 0.4% of current daily CO_2 emissions (global fossil CO_2 emissions were 35,753,305,000 tons in 2016 = 97,954,260 tons a day).

This might look like "just a drop in the ocean", but do you know of any other meal that offsets ANY of our daily CO_2 emissions? And if we successfully ramp up aquaculture to provide all humans with a meal-a-day, how about going a few stages further and aiming at other markets for nutritious proteins?

- The global animal-based protein supplements market size was valued at US\$ 12.61 billion in 2020 and is expected to expand at a compound annual growth rate of 7.4% from 2020 to 2028 as an increasing number of health-conscious consumers demand supplements with high protein content and nutritional value.
- Pet supplements global market size was valued at US\$ 1.9 billion in 2021 and is expected to expand at a compound annual growth rate of 5.9% from 2022 to 2030.
- Fishmeal can be made from almost any type of seafood, but is generally manufactured from wild-caught, small marine finfish that are being hunted to extinction. This market was worth US\$ 8.1 billion in 2020, has a predicted growth rate of 8.3% and is expected to be US\$ 15.3 billion by 2028.

- The global Soy Protein Market stood at US\$ 9.24 billion in 2021 and is projected to reach US\$ 10.96 billion in 2026. A large proportion of this being used to feed livestock animals. Substituting this with shellfish protein could release an enormous amount of scarce agricultural land for growing other human food (it takes an area of cropland 7 times the size of the European Union to produce feed for the livestock animals of Europe).

BUT, when you are looking at these potential future markets for mass-produced shellfish meat, REMEMBER that this shellfish meat is a BY-PRODUCT of our New Generation Shellfish Farming, for which the PRIMARY PRODUCT IS SHELL. And with careful management of the economics it should be possible to ensure that the CO_2 -polluter PAYS at least some of the costs of the production of that primary product shell. Rebuilding marine life has been proposed as a doable Grand Challenge for humanity, an ethical obligation and a smart economic objective to achieve a sustainable future. Securing that future for marine ecosystems suffering the effects of climate change is evidently a political challenge as much as an ecological or social one. The political limitations of conventional ecosystem governance have been recognised, but the immense promise of calcifier blue carbon science is so strikingly evident that it must be taken more seriously [5-8]. More than anything else this requires the recognition that cultivation of coccolithophores, corals, crustacea and molluscs on a massive scale would have the effect of removing a massive amount of CO_2 directly from the atmosphere; here, now and permanently, making a continued contribution to the health of the whole planetary ecosystem. It would be a criminal dereliction of duty if humanity failed to grasp this last opportunity to carry out this 'doable Grand Challenge'. And the sentence for such a criminal act is extinction. To carry out that 'doable Grand Challenge' we do not need revolutionary types of social organisation; what we need are market forces. If you don't think mere humans could accomplish what is needed in reasonable time, consider the oil well story. When the first oil well was drilled in 1859, in Titusville, Pennsylvania, they called the operation "Drake's Folly" and the driller "Crazy Drake", but soon the well "could produce in a few days the same amount of oil as a whaling ship on a four-year voyage". Now look where Crazy Drake has got us!

"Crazy shellfish farmer" could restore the atmosphere to the state that existed in 1859 during the next 160 years. All it takes is calcifier cultivation at the scale, with the zeal, and at the cost we have lately so readily and assiduously devoted to ripping fossil fuels out of the Earth.

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