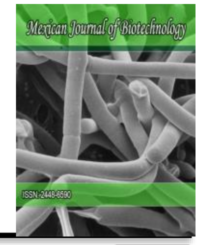
CICB
Publisher
Research Centre for Biological Sciences
(CICB), Autonomous University of
Tlaxcala, Mexico.

Mexican Journal of Biotechnology 2021, 6(1):92-128

Journal homepage:www.mexjbiotechnol.com

ISSN:2448-6590



REVIEW ARTICLE

Saving the planet with appropriate biotechnology: 3. The high seas solution

Salvando el planeta con biotecnología apropiada: 3. La solución de alta mar

Matthias Heilweck[1] & David Moore[2*]

[1]3, place Gouraud, F-68240 Kaysersberg, France [https://www.commonseagood.com/].
[2]School of Biological Sciences, Faculty of Biology, Medicine and Health, The University of Manchester, UK (**retired**).

*Corresponding author
E-mail address: david@davidmoore.org.uk (D. Moore)

Article history:
Received: 12 October 2020 / Received in revised form: 10 December 2020 / Accepted: / 23 December 2020 / Published online: 1 January 2021.
https://doi.org/10.29267/mxjb.2021.6.1.92

ABSTRACT

The case is made for greater use of the High Seas to replace forage fish with mussels in the diet of farmed fish and produce the increasing amounts of food that will be required by the growing human population, whilst at the same time pulling down carbon from the atmosphere with bivalve cultivation. The vision is to preserve the oceans as a healthy and sustainable food source for mankind by emphasising conservation and ecosystem balance beyond coastal waters. The plans are for huge (centralised) bivalve mollusc farming facilities on the high seas, using factory ships and offshore factory rigs (re-purposed disused oil rigs?) located on seamounts outside Exclusive Economic Zones and employing Perpetual Salt Fountains on the flanks of the seamount to bring nutrients to the farms. If properly designed (and the design and building capabilities exist throughout the offshore industries around the world), this will immediately provide (i) feed for animals and food for humans, (ii) sustainable marine ecosystems, and (iii) permanent atmospheric carbon sequestration in the form of reefs of bivalve shells.

Keywords: aquaculture, atmosphere remediation, bivalve farm, carbon dioxide, global warming, habitat restoration.

RESUMEN

Se apoya el hecho de hacer un mayor uso de la alta mar para reemplazar el pescado forrajero con mejillones en la dieta de los peces de cultivo y producir las cantidades cada vez mayores de alimentos que necesitará la creciente población humana, mientras que al mismo tiempo se extrae el carbono de la atmósfera con cultivo de bivalvos. La visión es preservar los océanos como una fuente de alimento saludable y sostenible para la humanidad haciendo hincapié en la conservación y el equilibrio de los ecosistemas más allá de las aguas costeras. Los planes son para grandes (centralizadas) instalaciones de cultivo de moluscos bivalvos en alta mar, utilizando buques factoría y plataformas industriales en alta mar (¿plataformas petrolíferas en desuso reutilizadas?) ubicadas en montañas marinas fuera de las zonas económicas exclusivas y empleando fuentes de sal perpetuas en las laderas de las montañas marinas para llevar nutrientes a las granjas de cultivo. Si se diseña adecuadamente (y las capacidades de diseño y construcción existen en todas las industrias en alta mar en todo el mundo), esto proporcionará inmediatamente (i) alimento para animales y alimento para humanos, (ii) ecosistemas marinos sostenibles y (iii) secuestro de carbono atmosférico permanente en forma de arrecifes de conchas de moluscos bivalvos.

Palabras clave: acuicultura, remediación de la atmósfera, cultivo de bivalvo, dióxido de carbono, calentamiento global, restauración del hábitat.

1. The context

Since ancient times, the seas have always been an abundant source of healthy food; this is about to change dramatically! Since World War II, the industrialisation of fishing has led to a drastic decline of the biomass of large, high trophic level fish; they are the carnivorous ones we prefer to eat, like tuna, swordfish, grouper, salmon or cod.

Since the 1990s or even before, the global wild fishing production has stagnated, despite greatly increased effort devoted to fishing with sonar-assisted super trawlers, fishing ever further from their home port and ever deeper in the oceans searching for new stocks to replace the already overfished traditional ones.

With traditional fisheries in danger of being fished out, aquaculture was considered as the best alternative to wild fishing and became the fastest growing food-producing sector, contributing efficiently to the food security of the world's expanding human population.

The other side of this coin, though, is that marine animal proteins are needed, in quantity, to farm aquaculture fish species. Consequently, forage fish, which means low trophic level fish, like sardines, anchovy, herring, sprats, capelin, and other organisms, like krill or even copepods, are now harvested from all possible ocean locations to feed this aquaculture industry.

This is environmentally destructive, because these low trophic species are already the subsistence food for about one billion people who live in coastal communities as well as all the other higher trophic animals that depend on a healthy marine environment like other fish, seabirds and sea mammals. Indeed, forage fish stocks are diminishing more and more, yet it is essential that the aquaculture industry remains able to produce healthy fish both for the human food markets, and for the open ocean to maintain healthy food chains and continue to support all the wild species from upper trophic levels, including, of course, all those other wild fish species humans also want to eat. We cannot use forage fish twice; their uncontrolled harvesting as fish food is not sustainable. Sea mammals, seabirds and wild fish populations are drastically declining, while forage fish are progressively replaced by jellyfish in the habitats these fish previously occupied, and artisan fisherfolk must work longer and sail further to catch less and earn less. The growth of world aquaculture is also unsustainable if forage fish stocks continue their decline because less wild fish means less natural fishmeal and fish oil can be included in farmed fish feed and the aquaculture farms are likely to produce a much poorer food for humans. Currently, we are duped twice!

Even without considering the effects of other marine threats like toxins, nutrient runoff eutrophication and petroleum or plastic pollution, this questionable practice of fishing down the food web (Fig. 1), if unchecked, could ultimately drive so many fish species to extinction that only coelenterates will be left to dominate the diminished ecosystems. Do you want to eat polluted jellyfish in the near future? we don't.

2. A novel idea

The originator of this idea, Matthias Heilweck, is from Alsace, France. For over 30 years, alongside his bread-and-butter job, oceanography has been the focus of his spare time. Although he lives about 1000 km away from the coast, he has always loved to read all the press articles and scientific publications he could find about this topic.

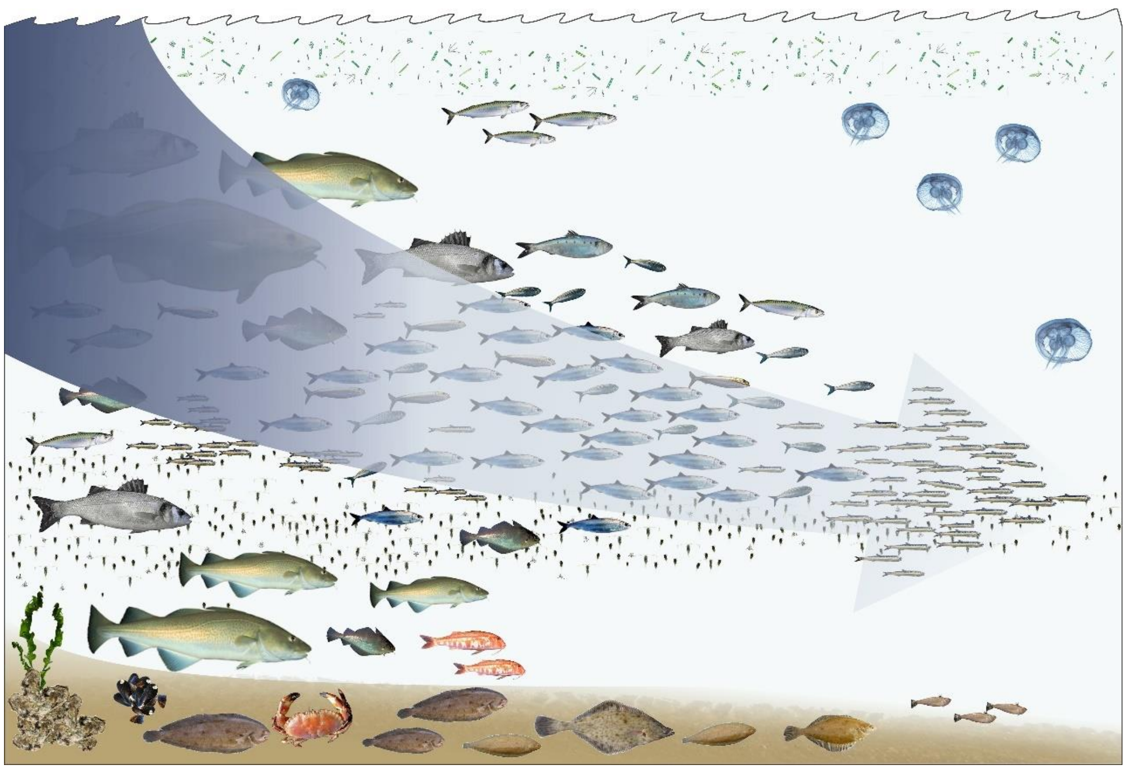


Fig. 1. Fishing down the food web, a North Sea perspective. Image © Hans Hillewaert inspired by the work of Daniel Pauly (Pauly et al., 1998) who describe the concept like this: "… Fishing down food webs (that is, at lower trophic levels) leads at first to increasing catches, then to a phase transition associated with stagnating or declining catches … [making] present exploitation patterns … unsustainable …" Image taken from https://en.wikipedia.org/wiki/Fishing_down_the_food_web under the Creative Commons Attribution-Share Alike 4.0 International license.

Being a pragmatic ecologist with a Cartesian preference for logical analysis he believes he's found a good way to help preserve the oceans as a healthy and sustainable food source for mankind. Between global pollution, overfishing and artificialisation of aquaculture, this may sound utopian, even pretentious. However, he decided to publish here the synthesis of his constructive, we hope, reflections about the topic and thereby confront critical analysis of them. His ideas are also explained on his website [view: https://www.commonseagood.com], which is, in a sense, his message in a bottle, optimistically thrown into the ocean of the World Wide Web, where it has bobbed around since June 8th, 2014, a World Oceans Day (Fig. 2)

Fig. 2. Heilweck's message in a bottle [https://www.commonseagood.com].

It all comes down to the development of a huge and healthy marine protein source, able to take over from the wild forage fish, those small pelagic fish of low trophic levels, which are harvested today in the open ocean solely to feed fish farms.

To achieve this the project still needs many relevant contributions from scientists, engineers, lawyers and other specialists. Obviously, huge funds will also be needed to finance the project. This is unavoidable, even simple operations on the high seas are tremendously expensive. But the goal is a sustainable, ecologically-friendly, healthy, and scalable production of aquafeed on the high seas, which is created from almost nothing and is not taken from anyone. That, you must believe, is worth paying for.

In the following sections of this review, we will explain in detail:

- WHY it should be done.
- HOW it can be achieved.
- WHERE it can take place.
- WHAT sort of marine organisms can be cultivated.

If you have the patience to follow this argument step by step through to the end, we are confident that you will admit that it makes sense.

3. Why should it be done?

There are two good reasons to proceed. First, because we must find new food resources to feed a growing human population; and second, because we need to keep the ocean resources (and, consequentially, ourselves) fit and healthy.

We have to find new food resources simply because there will soon be almost 10 billion humans living on this planet. As of August 2020, the current world population is 7.8 billion, and that population is projected to reach 9.8 billion in 2050 [source: the UN Twitter account at this URL: https://twitter.com/UN/status/877551686537027585]. This corresponds to a 25% increase over the next 30 years, and, obviously, current food production must also be increased by 25% over its current level if those new members of the human population are to be fed. It is clear that a 25% increase in agricultural production would require the adoption of broad open areas of currently unused land, as well as quality irrigation water in quantity. Whereas, in contrast, what we see around us is increasing urbanisation and desertification promoted by global warming. As these factors progress, available arable lands shrink dramatically. Our remaining forests and wilderness reserves are either highly coveted for agriculture or already acquired. Availability of fresh potable water, let alone irrigation water, is lessened by scarcity or pollution, and even our coastal seas are no longer free for additional exploitation.

Moore *et al*. (2020) point out that the fundamental problem is that there is not enough agricultural land on the planet to feed generously its entire current population, he states: '… Only about 7.5% of the Earth's surface provides the agricultural soil on which we depend for the world's food supply …'.

So, where then, is there still enough space and water that we can exploit? Well, we would say: "On the High Seas!"

Ocean fish resources are currently overexploited. For several years now, despite the technical efforts of the fishing industry which has driven capture fisheries ever further and deeper, production by wild capture has stagnated. At the same time, overall production of seafood has increased thanks to aquaculture. This activity is growing so rapidly that it is projected to overtake capture production in the foreseeable future (Fig. 3).

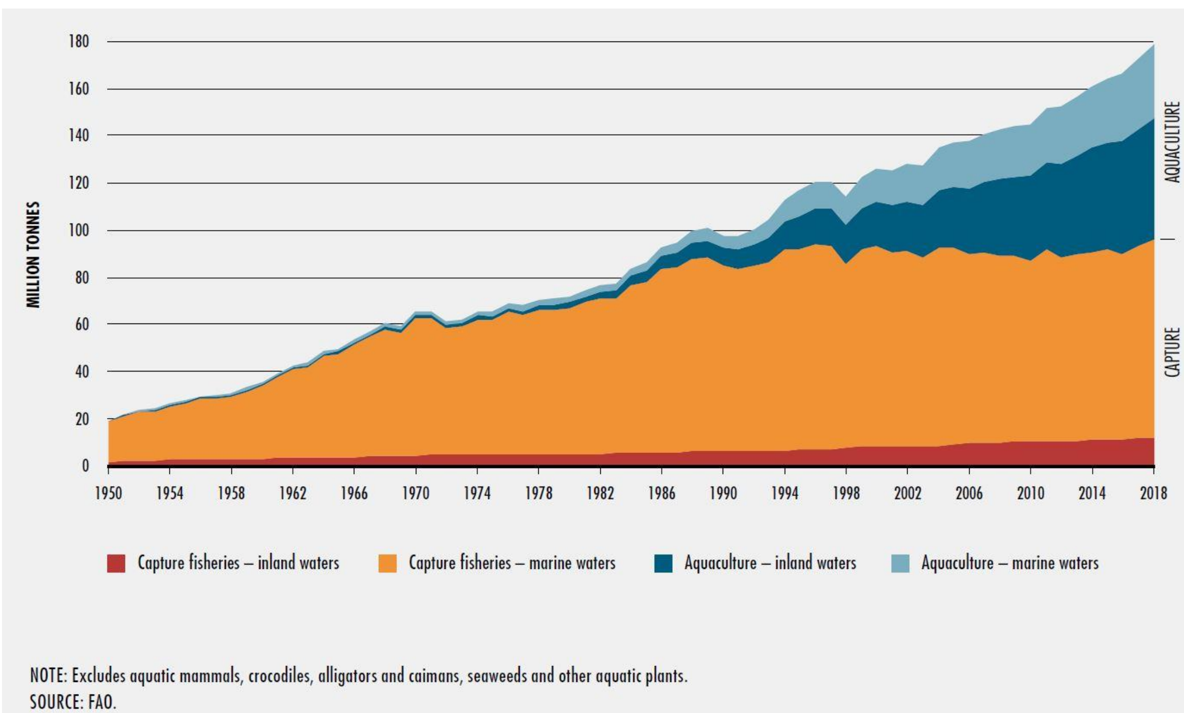


Fig. 3. World capture fisheries and aquaculture production 1950 to 2018, revealing the trend to stagnation of production through marine capture being compensated by increase in aquaculture production. Source: FAO report *The State of World Fisheries and Aquaculture 2020* (FAO, 2020).

The inland farming of herbivorous fish (carp, *Tilapia*) is still able to increase as long as appropriate locations can be found on land (though such locations are becoming rare); recycling water reduces the impact on fresh water supplies and the farming activity can even be combined with recreational activities. View Mark Driscoll's *Tasting the Future* website at this URL: https://tastingthefuture.com/2018/.

The marine farming of carnivorous fish (salmon, bass, cobia [Fig. 4, and view http://pacificreef.com.au/feed-supply/]) or shrimp is following a course that is more difficult to justify, despite its current success (view Columbia University's *Earth Institute* website: https://blogs.ei.columbia.edu/2016/04/13/making-fish-farming-more-sustainable/).

Fig. 4. Farmed cobia (*Rachycentron canadum*) being fed in a netpen. [View: https://thefishsite.com/articles/cultured-aquatic-species-cobia] Image source: Philip Chou/SeaWeb/Marine Photobank.

We believe that in the context of its global expansion, this food system bites its own tail, because as this sector expands increasing quantities of wild captured forage fish are necessary to feed the farms and, as mentioned before, these catches are declining. Consequently, the fish farming industry searches for substitutes for the fishmeal and the fish oil of their feed. Current attempts to feed farmed carnivorous marine fish with materials from terrestrial agricultural resources, instead of fishmeal and fish oil, may work technically, but have adverse effects on the wellbeing of the farmed fish, and thus on the health of our food through loss of the benefits derived from these well balanced natural compounds.

Once caught, forage fish does not preserve well in its raw state. The whole fish must be converted into fishmeal and fish oil (by cooking, screw-pressing and drying) if it is to be stored at room temperature for some time before use in aquafeed formulations. Fishmeal can be packed in bags. Fish oil for its part, is more fragile and must be hermetically sealed to avoid becoming rancid (view https://www.iffo.com/production).

Apart from the good amino acid profile of their constituent proteins (concentrated in fishmeal after the fish is processed) and their content of vitamins, minerals and trace elements, marine foods are healthy nutritional sources because, they contain high levels of long chain omega-3 polyunsaturated fatty acids (LC-PUFA, which is concentrated in fish oil after the fish is processed). Many research findings have demonstrated the value of omega-3 fatty acids in human nutrition (Bernasconi *et al*., 2020). LC-PUFA are known to lower blood pressure, slow the development of arterial plaque, reduce the chance of abnormal heart rhythm and the likelihood of heart attack and stroke. They are responsible for many functions in animal cells, such as signalling, cell membrane fluidity, and structural maintenance through which they also influence the nervous system (Gammone *et al*., 2019).

Fishes, indeed, all aquatic organisms, need large amounts of these omega-3 fatty acids in their diets, as they are the fundamental component of all their cell membranes. These essential LC-PUFA cannot be synthesised by the fish themselves, but are nearly exclusively produced by phytoplankton, the first and basic marine trophic level of the food chain in which the phytoplankton is assimilated by zooplankton, which is assimilated by the forage fish, and so on.

Without an appropriate amount of LC-PUFA, fish are much more sensitive to stress, prone to diseases, and must suffer greater loads of parasites like sea lice. In most aquaculture farms, to grow fish properly despite those issues, feed must be supplemented with antibiotics and the water treated with pesticides; both of which are ultimately ingested by the humans who eat this fish. After some significant scandals, the fish farming industry has sought to improve its methods using vaccines instead of antibiotics and lumpfish (sea lice eating fish) or mechanical treatments, instead of pesticides. Other ways of ongoing improvements are to go further offshore, where the stronger currents can sweep the pollution away, or to filter the water in recirculating aquaculture systems (RAS) on land. But the main problem of the low level of LC-PUFA in aquafeed remains. With a long chain omega-3 rich diet, farmed fishes are much healthier, which is desirable for the fish themselves, of course, but also for us, the eventual diners.

As with all terrestrial organisms, human nerve cell membranes require LC-PUFAs for efficient synaptic vesicle recycling (Marza *et al*., 2008). DHA (docosahexaenoic acid) is an omega-3 fatty acid that is a primary structural component of membranes in nerves in the human brain, cerebral cortex, skin, and retina. Further, EPA (eicosapentaenoic acid) is another important LC-PUFA which is essential for cardiovascular health. Consequently, the benefit to the human heart, eyes and brain is important enough for us to need to obtain LC-PUFA in sufficient quantities from our nutrition for healthy growth and development. It thus becomes quite critical to preserve farmed fish as a good LC-PUFA omega-3 source, particularly since a recent study has shown that the more LC-PUFA you ingest, the better your body feels (Bernasconi *et al*., 2020).

Others have come to this conclusion and attempts are in progress today to replace wild captured fish oil and supply more LC-PUFA omega-3 to the expanding aquaculture industry.

- Aerobic fermentation of heterotrophic microalgae discovered in muddy marine waters and fed with cane molasses in fermenters. *AlgaPrime DHA* [http://algaprime.com/] is produced by Corbion for BioMar. *Veramaris*, a joint venture of DSM and Evonik [https://www.veramaris.com/], produces a similar omega-3 algal oil using sugar derived from corn. Compared to forage fish reduction, it is a costlier process reserved for high-end markets. As a single supplement it does not provide a completely natural well balanced diet profile for the farmed fish because it contains only DHA (docosahexaenoic acid), lacking EPA (eicosapentaenoic acid) entirely.
- Growth trials with a genetically modified canola (rapeseed, *Brassica napus*) with an added gene from a microalga (Opsahl-Ferstad *et al*. 2003), started in Australia in 2019 (Nuseeds' Aquaterra™ [https://aquaterraomega3.com/]) and in the USA (Cargill Inc's Latitude™ [https://www.cargill.com/page/latitude]). This omega-3 canola technology promises great things. Quoting from the Nuseeds website: "… Grown on just a fraction of the world's existing, converted canola farmland, Aquaterra reduces pressure on the oceanic environment and delivers many nutritional, environmental and economic benefits. One

hectare of omega-3 canola provides the DHA yield from 10,000 kilograms of fish …" Use of omega-3 canola in fish farming has been well researched (Ruyter *et al*. 2019; and see https://nofima.no/en/nyhet/2017/11/new-oil-source-for-salmon/) and shows that the material is a good alternative to fish oil from capture fishing but two aspects continue to worry us. One is the fact that this feed supplement alone does not produce the natural well balanced diet profile for the farmed fish; because it is deficient in the very important EPA, and vitamins and minerals are also lacking. The other is the ethical consideration of using genetic manipulation to feed an animal that will become a primary human food. Acceptance, and even the definition, of 'GM foods' varies between administrations around the world. To quote from Opsahl-Ferstad *et al*. (2003): "… Combinations of basic understanding of gene function, transgene integration and expression, gene interactions, fatty acid metabolism in plants and animals and finally public acceptance have to be gained …" we are not sure that the public's acceptance has been, or even will be, secured as this is a highly politicised and emotive topic.

- Insect meal is often presented as a third alternative, but the breeding of Black Soldier Fly (BSF), which is the most heavily industrialised, produces only proteins and saturated oils of value, but not the scarce LC-PUFA. The latter could eventually be produced by mealworms given an appropriate diet, but their rate of development is probably too slow for this to be a profitable enterprise.

In any case, all these single compounds are only suitable for "modern" agri-food industries which are fond of cracking technologies down to their components. Thanks to mechanical denaturation processes (heat, freezing, pressure) and chemical denaturation processes (organic solvent, surfactant, acid, or alkali), each constituent of a natural food is separated into several low-cost nutrifunctional compounds, which in combination generate greater profits than the original (natural) food could have brought. Listed in catalogues, anyone can select different components to combine in any chosen food, with the required biochemical composition, aspect, flavour, and palatability. This is the origin of junk-food; "la malbouffe" as it is called in France, or ready to eat meals. A diet strongly suspected to contribute to the dangers of diabetes, cardiovascular failures and hormonal dysfunctions and their related chronic diseases.

The same occurs in the animal feed industry's pellet manufacturing. We are not only what we eat, we are also what we feed. Biochemists and nutritionists should use their knowledge to enhance food production in accordance with nature's laws rather than going deliberately against them. This plea comes from the heart. Let it be said, we believe in organic farming with some biodynamic precepts, agroforestry and multi-trophic aquaculture and the principles of permaculture to feed the world, rather than GMOs or industrialised farming and animal husbandry. To work with nature rather than against nature because if we replace intensive agriculture using the principles of permaculture, they will have positive effects on biodiversity, food production and carbon storage (Berners-Lee, 2019; Holmgren, 2011; Shepard, 2013).

The ambition is to develop a natural and healthy animal protein source in the present desert-like high seas. Enough to supply some long chain omega-3 rich feed to fish farms around the world (first to family ponds and small scale farms in developing countries). Hopefully, this would enable fish farming to provide a healthy food for humans, while leaving forage fish unmolested in the open sea to nourish penguins, seals, dolphins, whales, sharks, seabirds … and wild fish from the upper trophic levels to support artisan fisheries. The whole process of aquaculture has to be rethought in a pragmatic way to the benefit of all: fish farms, small-scale fisheries and natural marine ecosystems. In any case, industrial fisheries are rapidly approaching the time by which they must be finished. The main thread of these reflections is based upon an implacable logic: the better our aquaculture, the less we fish; and we let the oceans live.

4. How can it be achieved?

To begin, let us look at the issues we may encounter. The first issue encountered when operating any infrastructure on the high seas is likely to be the effects of **local weather conditions**. So, let us first choose the only ocean which seems not to be prone to major hurricanes: the South Atlantic (Fig. 5). It is also the ocean in which there are fewer fisheries and maritime traffic, so we should be able to find an unoccupied and safe place there.

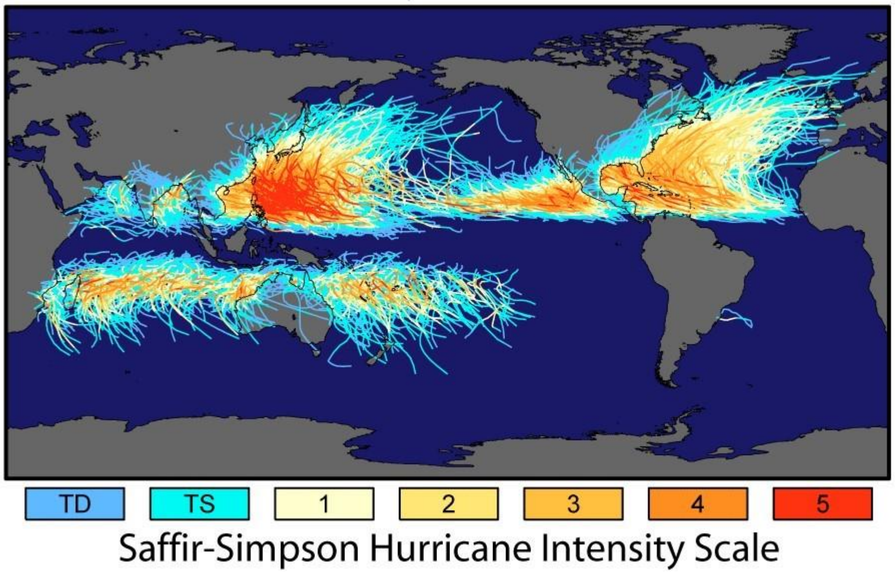


Fig. 5. Global distribution of the tracks and intensities of all tropical storms (hurricanes/cyclones) 1851 to 2006. Tropical cyclones do not form close to the equator and there is only one recorded tropical cyclone recorded along the Atlantic and Pacific coasts of South America (hurricane Catarina in 2004, rare and perhaps unique). Source: Historic Tropical Cyclone Tracks, NASA Earth Observatory [https://earthobservatory.nasa.gov/].

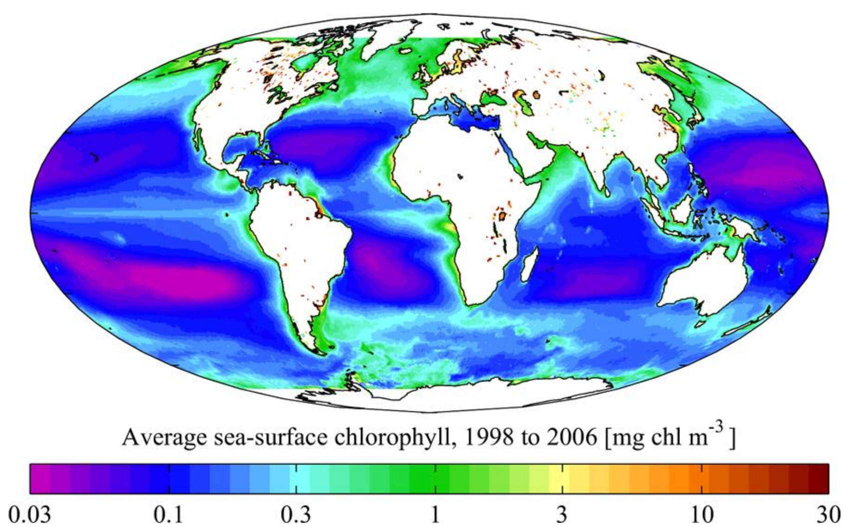


Fig. 6. Average sea-surface chlorophyll-a, 1998 to 2006 (mg chlorophyll m^{-3}). Chlorophyll-a is used as an indicator of phytoplankton biomass. Source: SeaWIFS Project [https://oceancolor.gsfc.nasa.gov/SeaWiFS/]. SeaWIFS (Sea-Viewing Wide Field-of-View Sensor) was a satellite-borne sensor, active from September 1997 to December 2010, designed primarily to quantify chlorophyll produced by marine phytoplankton.

The lack of mineral nutrients for phytoplankton growth is the second issue on the high seas in general, and in the South Atlantic in particular. Except in some eastern areas, where constant wind from the land causes upwelling, algal bloom, and consequential important fish production, it is a real desert out there. Anyhow, we must content ourselves with these desert areas because the naturally rich zones along the African coast are already occupied and exploited. Further west, the nutrients present in the photic zone (above 100 m depth where light is available; Fig. 6) are rapidly completely consumed by the photosynthetic activity of phytoplankton. In these conditions, the phytoplankton cannot multiply sufficiently to feed many zooplankton. That is why the high seas are biological deserts. No wind-driven currents are strong enough here to mix the layers, and the minerals are not massively renewed from the deeper layers, where they remain present in quantity.

The challenge now is to bring together the existing nutrients from the depths and the light from above. Logically, there are only two possibilities, take light down or bring nutrients up. We will consider both.

Take light down: Due to the aggressiveness of ultraviolet radiation from the sun in the upper sea layers, and also the constant adaptation of the controlled buoyancy of the phytoplankton, the optimal wavelength for marine algal photosynthetic activity is within the blue range of the spectrum, because this has the highest water penetration coefficient (Fig. 7) (Mascarenhas & Keck, 2018).

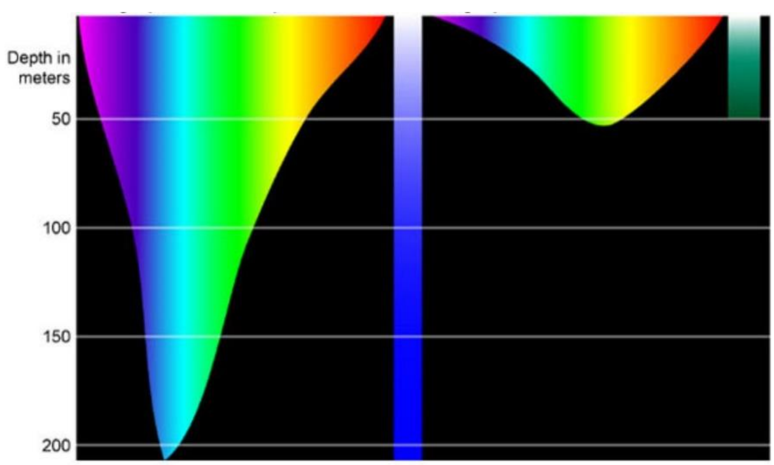


Fig. 7. Light penetration in the sea; open ocean at left, coastal waters at right. This diagram offers a basic illustration of the depth at which different colours of light penetrate ocean waters. Water absorbs warm colours like reds and oranges (long wavelength light) and scatters the cooler colours (short wavelength light).. Image courtesy of Kyle Carothers, NOAA-OE. Source: NOOA Ocean Explorer at: [https://oceanexplorer.noaa.gov/].

Luckily, thanks to today’s LED technology, we are able to produce exactly the blue light that is needed, with acceptable levels of energy demand (Fig. 8).

Furthermore, LEDs can be deployed easily in high pressure environments, because, unlike light bulbs, they are not hollow and cannot implode. But, even if we manage to illuminate properly a portion of the dark aphotic zone (below 100 metres depth) with arrays of blue LEDs, we still need to survey, handle, and fix a production process in these depths. This is feasible, but too constraining.

Fig. 8. Super Bright LEDs producing the blue light that is essential for marine algal photosynthesis. Image from the *GIZMODO* website [https://io9.gizmodo.com/] © 2020 G/O Media Inc.

***Bring nutrients up*:** Unfortunately, nutrients are diluted in great amounts of water, far too much to be pumped up with external (expensive!) energy to create an artificial upwelling. It would not be economically viable to spend so much energy. So, can we bring up colossal amounts of nutrient-rich deep-sea water without energy? Yes, we can!

Antarctic Intermediate Water (AAIW) is a nutrient rich, and low salinity water body, which characteristics are due, among other factors, to the mixture of seawater with mineral rich and fresh meltwater from the southern continental ice cap. These are the waters where the Antarctic life explosion takes place every summer. AAIW then flows slowly northwards in every ocean. In the South Atlantic, it meets warmer and saltier sub-Antarctic water at the convergence zone, 50°- 60°S. There, it sinks to a depth of approximately 1000 metres (3280 feet), gliding northerly over cold, salty and very dense bottom water.

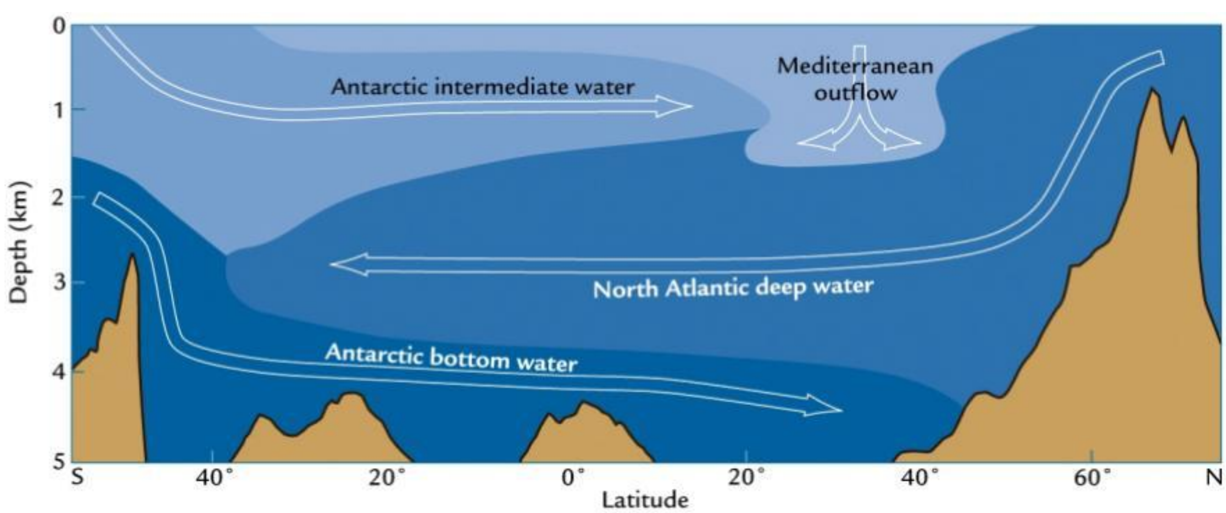


Fig. 9. Antarctic Intermediate Water currents (Courtesy: Ruddiman, 2014).

A large part of this water flows north-easterly to the South Atlantic Gyre, where it loses its characteristics by mixing. But a small part of it flows due north on the west side of the Atlantic, until it crosses over the submarine volcanic chain known as Vitória-Trindade (a volcanic hotspot chain), off the eastern coast of Brazil. AAIW lays at this depth and does not mix with the water layers above and below, even in this tropical region, where surface water becomes denser, due to evaporation causing increased saltiness (Fig. 9).

The sea stays stratified because the diffusion between the different water masses is low, no storms are strong enough in this region to mix the layers, and no constant wind from land forms an upwelling.

These conditions are ideal to set up a **Perpetual Salt Fountain**, an 'ocean curiosity' as described by Hank Stommel in 1956 (Stommel *et al*., 1956). This can be made to work where you have a warm and salty water mass above a colder and fresher one. The technique is to insert a vertical duct between these two layers, and then pump it out until the pipe is filled with the deep water. You can then stop pumping. The up flow from the lower layer will last perpetually, without any other external energy expenditure. This is because the heat energy difference between the water masses is conducted through the pipe walls, but the ***salinity difference*** remains unchanged, and it is the density difference caused by the salinity difference that drives the upward flow (Fig. 10).

This property has been validated recently in open ocean experiments in the Mariana Trench area of the Philippines Sea. A 0.3 m diameter, 280 m long soft pipe made of PVC sheet was used in the experiment and gave an upwelling velocity of 212 m day^{-1}. Subsequently it was demonstrated that the chlorophyll concentration around the pipe outlet was much greater than that in the surrounding seawater, providing evidence for increased primary production in the ocean by Stommel's perpetual salt fountain (Maruyama *et al*., 2004, 2011, 2013).

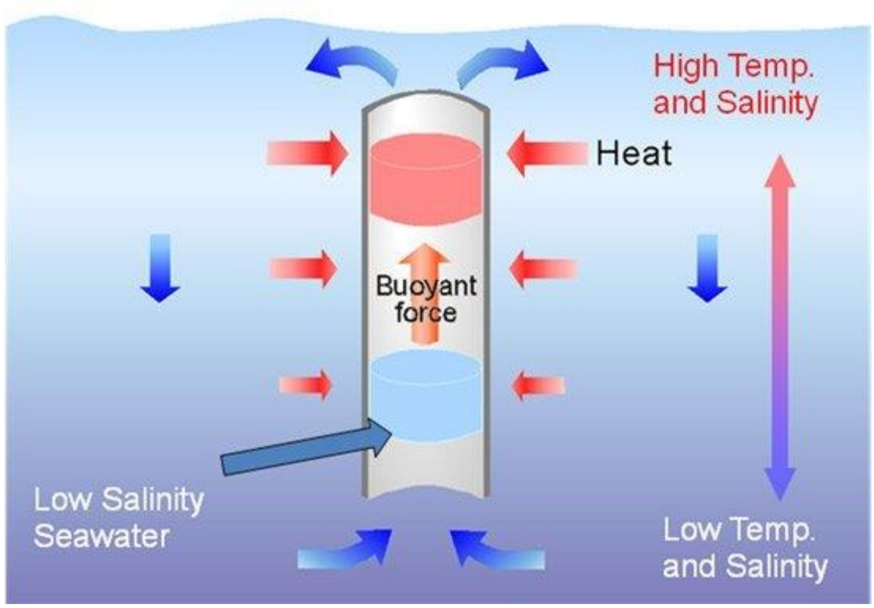


Fig. 10. Schematic diagram of a Stommel self-driven perpetual salt fountain. A duct links the very salty and warm water above to the low salinity colder water below. The salinity has the greatest influence on density so the cold water below has greater buoyancy and the salt fountain can be very strong. The system allows nutrients to be brought to the surface without expenditure of energy. Image courtesy of Prof. Shigenao Maruyama, Institute of Fluid Science, Tohoku University, Sendai, Japan [http://www.ifs.tohoku.ac.jp/maru/].

Similar experiments in Chinese ***coastal*** waters were also successful (Fan *et al*., 2020). These experiments were conducted in the oligotrophic Aoshan Bay, in the Shandong Province of China. In this case, a solar-powered, air-lift system was used to lift the nutrient-rich bottom water to the surface and the results show that the growth of seaweeds in a kelp farm was stimulated by this artificial upwelling. The authors calculate that an extra carbon removal potential of 14.8 thousand tons in Chinese coastal waters might be expected if their system were to be applied along the Chinese coast.

Furthermore, AAIW, found today at 1000 metres depth in the tropical zone of South West Atlantic, was in contact with the atmosphere about 300 years ago, in other words, long before the Anthropocene, and the wide dissemination of anthropogenic pollutants. Even with the inevitable transfers between water layers, caused for example by the daily vertical migration of plankton, **the concentration of anthropogenic pollutants in AAIW should remain insignificant**. By contrasting the present state of seafood contamination with heavy metals and persistent organic pollutants (POPs), these waters constitute a very attractive aquafeed production environment.

For several years now, the World Health Organisation has recommended us to eat fish for its healthy omega-3 content, ***but not more than twice a week, because of its pollutant content***. Just before Christmas 2016, a leading French consumer association revealed also that organic farmed salmon has higher contaminant levels than conventional farmed fish (both, luckily, well below WHO standards), due to a higher fishmeal inclusion in their feed (issue No. 521 of the magazine ***60 millions de consommateurs***, in a report entitled *Saumon: carton rouge sur le bio n'est pas irréprochable* [https://www.60millions-mag.com/]).

In contrast to the assertions of this article, the (still relatively low) contamination of fishmeal is not due directly to wild forage fish, but more likely to the 30% sourcing of trimmings from higher trophic level fishes, in which pollutants accumulate most heavily, when packaged in the filleting factories. Nevertheless, it is time to take serious steps to reduce the currently observed contamination levels of farmed fish with heavy metals and POPs.

Another issue is to build a floating infrastructure with, at least, a 1000 metres deep anchorage, or with dynamic positioning. This is a quite outrageous plan if you consider the scale of the engineering needed to reach the sea floor and the production levels we are aiming for. But the plan is made more realistic by seamounts, and more specifically guyots (also known as tablemounts) with a flat top; extinct volcanoes rising up from the seafloor, sometimes almost to the surface. Such a guyot is perfectly suited **to support an infrastructure on its top, and pipes along its slopes**. In addition, due to Taylor columns effects (arising because of the Coriolis forces), seamounts have the particularity to let the isotherms rise and form a vortex that retains the surrounding waters. This phenomenon allows us to find AAIW at less deep levels and, after being raised through the Perpetual Salt Fountain pipes, to keep it above the seamount for a sufficient time for exploitation.

A last issue is the provision of the **required energy supply** so far away from the continental shores. Leaving aside nuclear power, which some consider a lethal activity for mankind, and fossil fuels which have no real future anymore, we must consider renewable power sources.

- Solar power: solar panels, deployed on a large area, are certainly too vulnerable in an open sea environment (at the moment).
- Wind power: wind turbines have already been anchored off-shore but may provide only an intermittent power supply.

- Wave power: Wave Energy Converters are fragile mechanical devices and are also unable to provide a regular supply.
- Ocean current power: marine turbines need a strong current to be efficient and it is better to avoid strong currents for the purposes of this project.
- Power from osmosis: semipermeable membranes are expensive; cleaning chemicals are needed, and the system is complex to handle.
- Power from temperature gradients: Ocean Thermal Energy Conversion plants are also very sophisticated systems and need chemical refrigerants.

If none of these are acceptable candidates, what else is there? We suggest geothermal energy for the installations we have in mind. If we locate our infrastructure just above an extinct volcano, we could bring the Earth's internal heat as a power source rising from the seafloor almost to the surface.

5. Where could this take place?

The Brazilian continental margin includes several volcanic islands and submerged volcanic seamounts, and there is a suitable location for our purposes in the Vitória-Trindade Seamount Chain, which is located off the central coast of Brazil. Starting 175 km off the coast of Espírito Santo State and extending for 950 km eastward, the seamounts are disposed almost linearly at 20° and 21°S (Fig. 11)(Alves, 1998; Almeida, 2006; Mohriak, 2020).

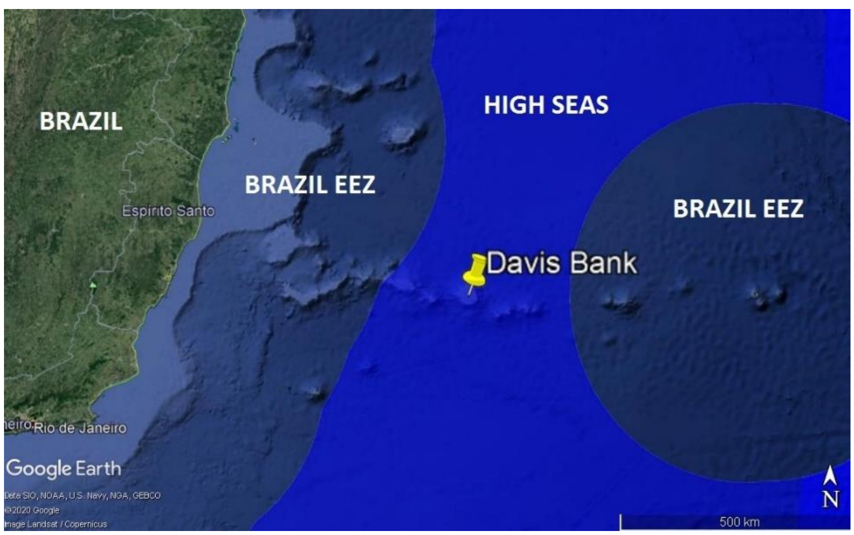


Fig. 11. Davis Bank, a guyot (or seamount) situated in the centre of the Vitória Trindade Chain, between two of Brazil's EEZs (Exclusive Economic Zones), the continental one and that enclosing the islands Trindade and Martim Vaz. (Source: KML file of Flanders Marine Institute (2020), Maritime Boundaries Geodatabase: High Seas, version 1, available online at http://www.marineregions.org created on Google Earth with the author's annotations).

Many of these seamounts rise higher than 2.5 km from the ocean floor, with more than half reaching the surface layers that receive enough light for photosynthesis to occur (the euphotic zone) (Motoki *et al*. 2012). The mechanism of formation of these seamounts and islands has been linked to volcanic episodes dated from the Late Cretaceous (100.5 to 66 million years ago) to the Pleistocene (2.58 to 0.012 million years ago), with the Trindade Archipelago, at the easternmost end of the Vitória-

Trindade Seamount Chain, being the youngest volcanic eruptions (2.8 to 1.2 million years ago)(Geraldes *et al*., 2013).

A suitable guyot is located in the Vitória-Trindade Chain, which is called the **Davis Bank**. In the tropical southwest Atlantic, it is the only suitable seamount which does not belong (yet) to a national Exclusive Economic Zone. It rises from 4000 metres on the sea floor to less than 50 metres depth (160 feet) and has a very large flat top of around 90,000 hectares (222,000 acres)(Figs 11 and 12).

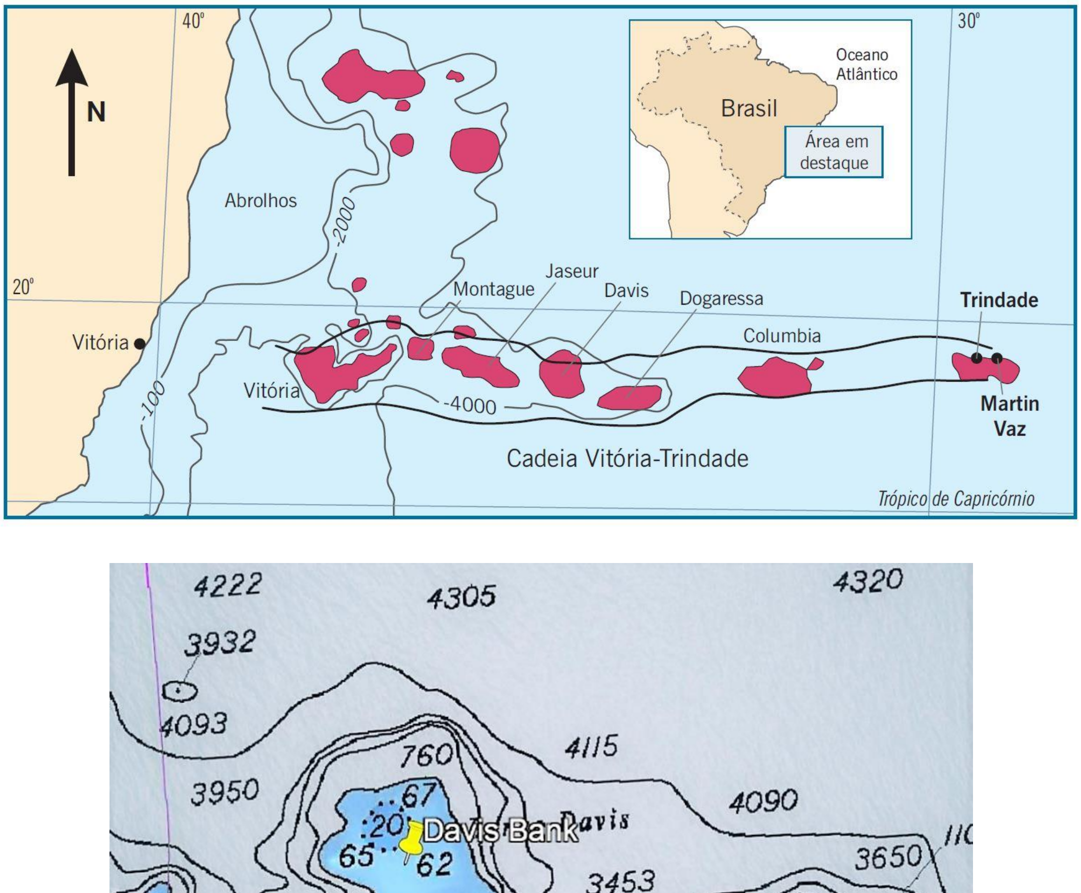


Fig. 12. **Top**: Geographical location of the Vitória-Trindade Seamount Chain, which is located off the central coast of Brazil. From Almeida, 2006. **Bottom**: Details of bathymetric contours around Davis Bank, the seamount (or guyot) situated just off Brazil's continental EEZ. This map was generated on Google Earth with a KML file specifically created for Matthias Heilweck by Marine Geogarage (with the data of Centro de Hidrografia da Marinha do Brazil) to show the bathymetry of Davis Bank, from 4000 m on the seafloor to between 20 m and 60 m from sea level.

The Brazil Current, a warm water current that flows south along the Brazilian coast towards the Río de la Plata, is the western boundary current of the South Atlantic subtropical gyre. It transports warm water pole-wards and as it passes through this region it has relatively low nutrient availability. These environmental conditions favour mixotrophs (flexible organisms that can kill and eat other plankton as well as photosynthesising), heterotrophs (consumer organisms unable to photosynthesise), or diazotrophs (nitrogen-fixing microbes). A plankton survey near the Vitória-Trindade Seamount Chain identified 175 taxa, representing Cyanobacteria (photosynthetic bacteria, some nitrogen-fixing), *Bacillariophyta* (diatoms), *Dinophyta* (dinoflagellates), and *Ochrophyta* (brown and golden-brown algae). The greatest species diversity was seen among the dinoflagellates (Lubiana & Dias Júnior, 2016). These seamounts therefore appear to be hotspots of bacterial and alga-like primary productivity. The waters around them also contain large stocks of commercially important fish (Meirelles *et al*., 2015; Pinheiro *et al*., 2015). Indeed, Meirelles *et al*. (2015) conclude that the Vitória-Trindade Seamount Chain "… represent important hotspots of biodiversity that deserve further conservation actions." We couldn't agree more!

6. What sort of marine organisms can be cultivated?

The core of all production in the sea is phytoplankton, which multiplies rapidly, subject to presence of mineral nutrients and light. From there on, a short trophic relationship with an organism, which has a good conversion efficiency, would be the most effective and healthiest way to produce anything.

Sessile filter feeders like the bivalve molluscs given the common name 'mussels' are good candidates, because they belong to the second marine trophic level, they do not expend energy swimming and, being sessile, they cannot escape from any infrastructure into which they are introduced. Before going further, we should point out that by using the name 'mussel' we are not limiting attention to a single species or even one genus of organism.

The name 'mussel' is a common name used for members of several ***families*** of bivalve molluscs, from freshwater as well as saltwater habitats. The common feature of the bivalves so named is a shell whose outline is elongated and **asymmetrical**, whereas shells of other clams are rounded or oval but ***symmetrical***. We will continue here to use the name 'mussel' in this broad sense of a ***sessile*** bivalve species best suited to the conditions of the location in which it is to be farmed. Variability of shell shape in bivalves is an adaptive feature allowing the animals to respond to less favourable environmental conditions with thicker and heavier shell valves than normal, that can be closed tightly to protect the body. The shell length, a factor often measured to represent the animal's size, does not always accurately reflect the soft tissue content because growth of shell and soft tissue does not occur simultaneously; generally shell growth precedes the growth of soft tissue. During spawning or food shortage, internal energy reserves are consumed while the shell may continue to grow. Salinity, temperature, and food supply have the greatest influence on this variability. In intertidal bivalves, shell weight is supported by a smaller biomass in animals located high on the shore than in those at the low water mark. A response determined by the need to provide space within the shell for filter feeding by the gills (Seed, 1968, 1980; Hilbish, 1986; Aypa, 1990; Franz, 1993; Gimin *et al*., 2004; Telesca *et al*., 2018). The ecophysiology of bivalves has been modelled extensively with simulation models in which the culture ecosystem is viewed as distinct compartments of variables (e.g. shell, soft tissue, phytoplankton, etc.), between which quantified flows of energy or materials occur (Scholten & Smaal, 1998, 1999; Filgueira *et al*., 2015; Fuentes-Santos *et al*., 2019).

The short trophic relationship between primary production of phytoplankton and production of mussels assimilating it, combined with the very pure AAIW quality, are the unquestionable guarantee of the **lowest level of anthropogenic pollutants at the end of the cultivation process**.

Mussel aquaculture has been practiced for centuries, even millennia, because it is rather an easy culture. They multiply profusely, attach themselves on any rough surface, natural or artificial, and feed on any organic matter suspended in the water they filter. Several cultivation techniques are used nowadays and practical advice is widely available (Lovatelli, 1990; Utting & Spencer, 1991; Helm *et al*., 2004).

Wikipedia [https://en.wikipedia.org/wiki/Mussel#Culture_methods] lists the following farming methods:

- **Bouchot culture**: Intertidal growth technique, or bouchot technique (also known as pole culture or stake culture): wooden (or other) pilings, known in French as bouchots, are planted in the shore; ropes, on which the mussels grow, are tied in a spiral on the pilings; some mesh netting prevents the mussels from falling away. This method needs an extensive tidal zone to enable work on the poles at low tide. Bouchot-grown mussels have a longer shelf life, as the animals are habituated to being out of the water at low tide.
- **On-bottom culture**: On-bottom culture is based on the principle of transferring mussel 'seed' (spat) from areas where they have settled naturally to areas where they can be placed in lower densities to increase growth rates, facilitate harvest, and control predation, or which are simply owned by the farmer. This method requires minimum investment. It is effectively a 'free-range' cultivation but has the disadvantages of the natural environment: heavy predation by oyster drills (whelks), starfish, crabs, as well as siltation (accumulation of fine sand and clay particles in the animal, which reduces market value), poor growth and relatively low yields per unit culture area.
- **Raft culture**: Raft culture is a commonly used method throughout the world. Lines of rope-mesh 'socks' are seeded with young mussels and suspended vertically from a raft. The specific length of the socks depends on water depth and food availability. Principal advantages of this type of culture are reduced predation, utilisation of planktonic food at all levels of water, and minimum siltation.
- **Longline culture (rope culture)**: Mussels are cultivated this way extensively in Galicia (Spain) and Chile, as well as in New Zealand (Fig. 13). The conventional method is to attach mussels to ropes which are hung from a rope back-bone supported by large plastic floats. The most common species cultivated in New Zealand is the New Zealand green-lipped mussel. Longline culture is the most recent development for mussel culture and is often used as an alternative to raft culture in areas that are more exposed to high wave energy. A long-line is suspended by a series of small anchored floats and ropes or socks of mussels are then suspended vertically from the line.

Mussel production costs are highly variable, depending on temperature (which affects growth rate), carrying capacity (availability of nutrients), cultivation method, technical automation, labour costs and productivity, rate of predation, availability of mussel 'seed' (spat), and offshore transport costs. Using long lines is the most productive technique for mussel aquaculture because it takes advantage of the volume in the water column, instead of a surface. However, this production method, intended for human consumption, is too expensive, and needs to be adapted to suit aquafeed production. Several sorting and cleaning stages essential for harvests intended as human food can also be abandoned, freeing a lot of time and money. The long lines themselves are too expensive in their present form, and also need to be re-designed.

Despite the reservations just expressed, **long lines mussel farming is by far the world's most productive breeding method**, currently yielding 150 to 300 metric tonne, per hectare per year. To put these figures into perspective, beef production is only around 0.340 tonne per hectare per year, almost a thousand times less! With mussels on long lines, we can reasonably forecast (if the carrying capacity is given) a production between 3 to 6 million tonne of mussel flesh (50% to 75% is shell) in a square of 90,000 ha, like the flat top of Davis Bank.

Fig. 13. Rope cultures of blue mussel (*Mytilus edulis*). Source: The MARICULT Research Programme [http://kodu.ut.ee/~olli/eutr/html/htmlBook_111.html#id7]. See also Olsen, 2002.

This figure for the potential yield can also be compared to the 5.5 million tons of Peruvian anchovies caught in 2018, which is world's largest fishery dedicated to the production of fishmeal and fish oil. These were their highest landings since 2011 and unlikely to be surpassed, due to government conservation policies that limit the total allowable catches. Moreover, 2018 did not experience the famous El Niño event, which periodically occurs and results in a temporary collapse in yield of this fishery.

However, because of the relative ease of culture, some aspects of the biology of mussels, such as their most efficient diet, have only been poorly documented. We know that mussels filter and ingest plankton and other organic particles from 5 to 15 microns. Diatoms, the main intake, provide DHA (the omega-3 fatty acid that is a primary structural component of membranes in nerves in the human brain – see above) and flagellates provide EPA (eicosapentaenoic acid, another omega-3 fatty acid that is good for cardiac health). Control of the diet of mussels, neglected until now, is all important here, especially if it can be manipulated.

Each mussel filters nearly 100 litre of water per day. Retaining all the particles present in the water, its food conversion factor can fluctuate between 30 and 80%. That means mussels produce between 20 and 70% faeces (which pass through the digestive system), or pseudofaeces (materials which are immediately rejected). These sink and pollute the surroundings, because the organic content is not degraded by aerobic bacteria during sedimentation. This is especially important when the sea floor is not very deep, which is the case in most coastal areas where mussels are farmed.

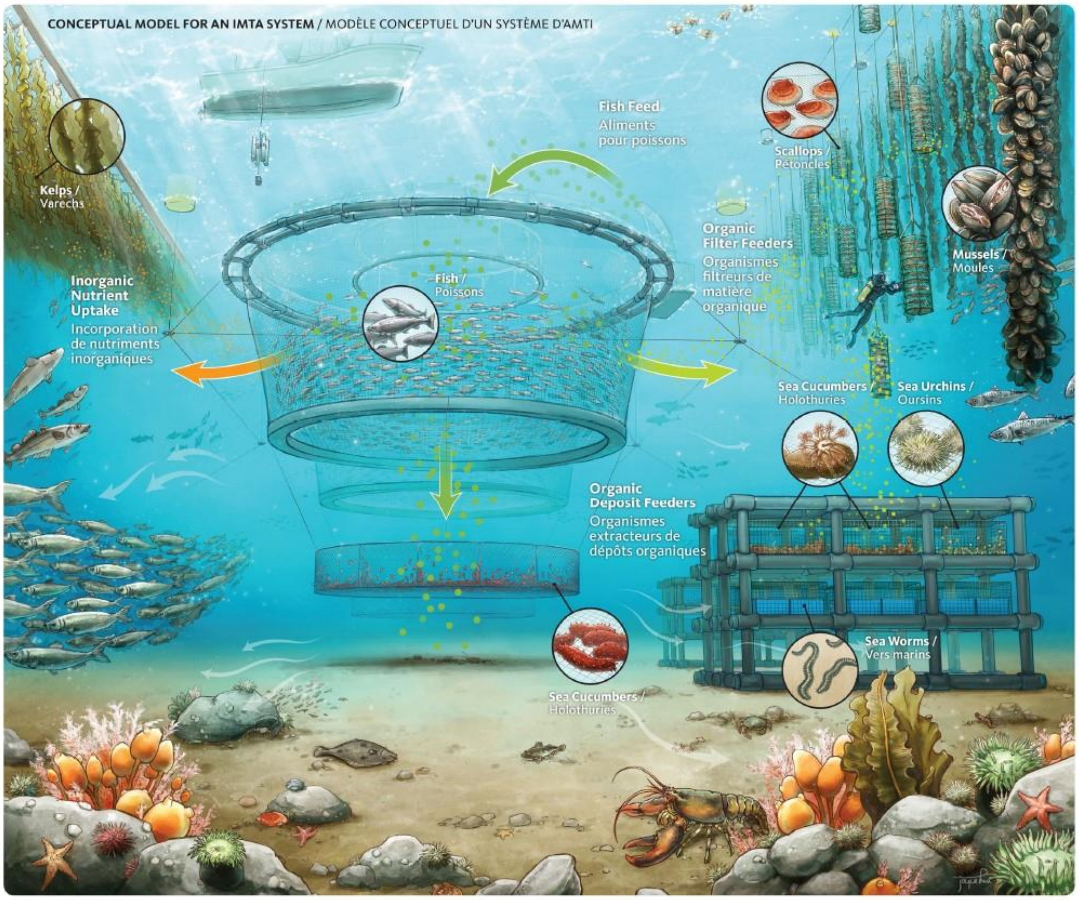


Fig. 14. This illustration depicts a conceptual model for an Integrated Multi-Trophic Aquaculture (IMTA) System. Small orange dots and orange arrows show the flow and uptake of inorganic dissolved nutrients from the salmon finfish net pen (centre) towards the Kelp rafts (at left). White arrows show the direction of the water currents within an IMTA system. Green dots and arrows show the flow and uptake of organic particulate nutrients by filter feeders such as scallops and mussels (at right) as well as deposit feeders such as sea cucumbers, sea urchins and sea worms. Organic nutrients are shown for both fine particles (represented by smaller and lighter green dots) and large particles (represented by larger and darker green dots). Source: © Fisheries and Oceans Canada, drawn by Joyce Hui) [https://dfo-mpo.gc.ca/aquaculture/sci-res/imta-amti/index-eng.htm].

When the faeces accumulate on the sea floor, digestion depends on anaerobic bacteria, which have a negative impact on ecosystem health. That is why knowledge of the most efficient diet for mussels is so important. Especially if we can influence this food conversion factor and the nature of the metabolised substances, by using the appropriate phytoplankton mix to feed the mussels. In this project, the most favourable phytoplankton species could be injected into the rising nutrient-rich AAIW passing through the salt fountain pipes, allowing them to multiply on their way up, thanks to strings of blue LEDs within the pipes. In this way it should be possible to control the diet of cultivated mussels produced by the facility, to minimise faecal output and **maximise omega-3 fatty acid production**.

Now we have the framework. But it will not work as described so far because of the environmental footprint of such a huge mussel farm. To avoid contamination, it still needs to be distributed between several places, or at least trophically compartmentalised in some way, by cultivation of macroalgae ('kelp forests') for example, to establish greater biodiversity among the species cultivated so that the 'mussel farm' becomes a self-sufficient ecological community or biotope. This approach is called ***Integrated Multi-Trophic Aquaculture*** (IMTA) where the waste products of one species are recycled as feed for another (Milhazes-Cunha & Otero, 2017) (Fig. 14).

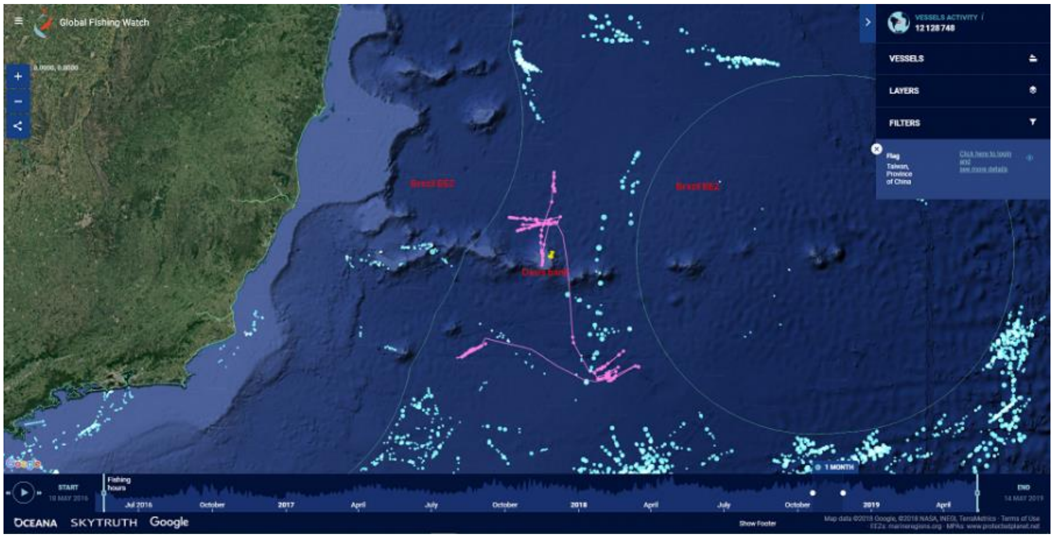
Mussel faeces cause pollution problems in most of today's monoculture farm locations. To avoid this, the soluble faeces can be assimilated by kelp or other macroalgae, and the solids can be assimilated by scavengers on the sea bottom like sea cucumbers (see Fig. 14 legend). These will also strongly contribute to the project's viability, because of their importance in Asian cuisine and medicine. You can read more about it on the website of Fisheries and Oceans Canada's IMTA Research Laboratory at this URL: https://dfo-mpo.gc.ca/aquaculture/sci-res/imta-amti/imta-amti-eng.htm.

However, despite IMTA techniques, such a mussel farm will lead to a huge threat for the existing biodiversity of this rhodolith covered seamount, which counts several species of algae, corals, crustaceans, sponges, fishes, some of which are endemic (not found elsewhere) (Pinheiro *et al*., 2015; ***and view*** Hudson Pineiro's YouTube video at [CLICK HERE]). In short, the Vitória-Trindade Chain that includes Davis Bank is a rich reef biotope, but not without its threats.

To quote Pinheiro *et al*. (2015): "… The structure of fish assemblages was similar between islands and seamounts, not differing in species geographic distribution, trophic composition, or spawning strategies. Main differences were related to endemism, higher at the islands, and to the number of endangered species, higher at the seamounts. Since unregulated fishing activities are common in the region, and mining activities are expected to drastically increase in the near future (carbonates on seamount summits and metals on slopes), this unique biodiversity needs urgent attention and management."

Since this was written, carbonate mining to provide fertilisers for Brazilian sugar-cane plantations has occurred there, together with mining trials of cobalt-rich crusts. Moreover, for several years now, fleets of fishing vessels from China, South Korea, Portugal, and Spain commonly work there (Fig. 15). If these fleets use bottom trawls, the reef might already be in bad shape. we do not know how this paradise looks today, but if it is still pristine despite these damaging attacks, we may perhaps choose a less space-requiring marine organism than bivalve mollusc farms for our purposes. Copepods are a good candidate, especially species of *Calanus* (Fig. 16). From 13,000 species of known copepods, 10,000 are marine and 5,000 of them are nonparasitic and free living zooplankton (like *Calanus*). Populations of these 1-2 mm crustaceans are so large that they represent a considerable marine biomass and are, in nature, a crucial link between energy-producing phytoplankton and fish. Like mussels, they belong to the second marine trophic level. In spring, they aggregate together in huge swarms near the surface, until seawater becomes like a syrup that the baleen whales scoop into huge mouthfuls.

A single copepod can catch and consume a few hundred thousand phytoplankton cells per day, clearing about a million times their own body volume of water. They feed at the surface at night to avoid visual predators and eventual toxic emanations from phytoplankton. At daytime, they sink several hundred metres down to stay protected. In Polar Regions, they sink to a thousand metres depth to hibernate during the cold season and live on their reserves, accumulated during the summer.



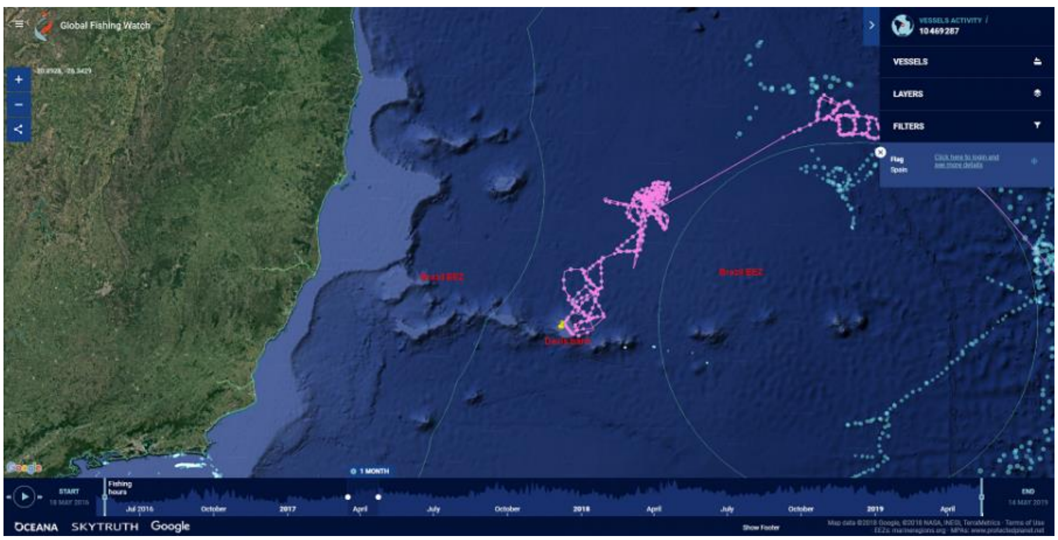


Fig 15. Top: Chinese fishing vessel tracks on Davis Bank in November 2018; bottom: Spanish fishing vessel tracks on Davis Bank in April 2018. Screen captures made of observations on *Global Fishing Watch* [https://globalfishingwatch.org/].

Fig. 16. The copepod *Calanus* sp. Photo courtesy of Terje van der Meeren, Institute of Marine Research, Bergen, Norway (Escobar-Lux *et al*., 2019).

This is why their metabolism allows them to build up a very high protein and LC-PUFA content. To be able to sink, they change their oils into denser fats/wax esters. They also accumulate astaxanthin, a lipid soluble carotenoid, well known for its anti-oxidant properties, which enables them to hibernate with preserved stocks of nutriments. Astaxanthin is also the substance that gives the orange-red colour to wild salmon flesh. Fish feed is currently supplemented with synthetic astaxanthin to avoid rancidness and give the right colour to farmed salmon flesh.

With a view to breeding *Calanus* spp. for fish feed, some interesting properties can be highlighted:

- They are already natural fish feed, a wholesome feed for aquaculture.
- They aggregate together naturally and can thus be easily harvested.
- They have a very high protein and LC-PUFA content, naturally well balanced with all needed micronutrients.
- Bound as wax esters, the LC-PUFA are much better assimilated than those of fish oil and lead to very pronounced positive effects on important metabolic parameters.
- Thanks to their astaxanthin content which acts as a 'self-preservative', they may not need to be processed into meal and oil to be stored at room temperature.

Our expectation is that we should be able to breed swarms of *Calanus* spp. inside the Perpetual Salt Fountain pipes, harvesting them at the top outflow to avoid threat to the environment. A proportion of the harvest would be returned to the bottom of the pipes as inoculum for the next growth cycle.

Obviously, a great deal more research needs to be done but the scientific work to which we refer here suggest the project has a solid base to counteract the challenges of fish farming sustainability and preservation of the biological productivity of the open oceans. Pragmatic ecology and oceanology suggest we must start these efforts by installing perpetual salt fountain pipes on Davis Bank.

7. Our Vision about the High Seas

In our opinion, in the very near future, providing food for the whole of humanity will become the main challenge we face as a global species. Not gold, diamonds, oil or gas, not rare earth elements nor even personal data; the overriding problem that is rushing towards us is just the provision of food for all of us on earth. Jewels are not a necessity, neither are gluttonous cars or the latest smartphones, for us to live well. On the other hand, food shortages happen now and cause populations to migrate and create deadly conflicts. Driven by hunger, each of us can steal and fight. The vital need for food supplants everything else. Because of the expected global resource depletion, food supplies will become the 21st century's first means of exercising political power and influence. The United Nations Organisation (UNO) should be able to count on a supranational food production, which we believe this project can provide. **Food sufficiency for all is the first guarantee of peace**.

We would like to see the huge amounts of animal proteins that our project is likely to produce when fully developed directed first towards family-based and small scale fish farms, in a manner that allows redirection easily and quickly to communities in need. At the same time, mussels are essentially an excellent food for humans. As the programme expands, a part of the production could be put at the disposal of the *World Food Program* (WFP). To ensure that no national power can interfere, this production needs to be directly accountable to UNO in the framework of "**the common heritage of mankind**" (Bollier & Helfrich, 2013; and view: http://wealthofthecommons.org/home).

This concept was first defined legally in 1982 at Montego Bay by the *Convention on the Law Of the Sea* (UNCLOS), giving birth to Exclusive Economic Zones (EEZ), inside 200 nautical miles off the coasts, in which resources belong to the contiguous country, and also to the *International Seabed Authority* (ISA), which was charged with managing the mining resources outside EEZ (called The Area, which is the seabed outside EEZ) for humanity. The ISA gives mining licenses to countries or companies, and surveys their activities in terms of pollution, together with their benefits in term of sharing. Some mining licenses are already active, but the resulting obligations remain unclear, though is true that the opportunity to exploit polymetallic nodules, hydrothermal vents or cobalt crusts is technically and economically not yet mature. Seabed mining will really start first inside EEZs, on the continental shelf, in which locations it is clear that the benefits will never be shared for the common good.

But in the water column outside EEZs, no legal framework protects the marine biodiversity. New industrial fishery activities, such as deep sea bottom trawling or fish aggregating devices (FAD), are already widely exploited, and plunder the sea for the interests of a few. This remaining free area (on a first-come, first-served basis) called The Commons (the water column outside EEZ), covers half of our planet and belongs to all of us!"

The *High Seas Alliance*, which counts more than 40 environmental NGOs, mobilised since 2011 to initiate a competent authority, which can regulate *The Commons* in the interest of the public good. An UN ad-hoc and open-ended informal working group was first charged to find issues for the governance of marine Biological diversity *Beyond areas of National Jurisdiction* (BBNJ). A major step was taken on January 2015 when the United Nations agreed to begin negotiating a legally binding treaty to conserve marine biodiversity in the high seas. The first round of negotiations started at the end of March 2016 for two weeks, but the talks are limited to the definition of Marine Protected Areas and the global sharing of biological patents derived from marine organisms. It is still good news, but what will be the state of the oceans when a binding resolution is adopted, which, at normal rates of progress in such matters is unlikely to happen in less than 10 years? Market forces are likely to act much faster.

Beyond EEZ, everybody is free today to build an infrastructure, an artificial island, the status of which is ruled by the owner’s home nation, or a flag of convenience. Matthias Heilweck, being already a dual French and German citizen, lacks only the other 191 UN member nationalities to be an international representative! To assure the international global status of the high seas as a Common Heritage of Humanity, we need a supranational ***High Seas Authority***.

Davis Bank, the perfect guyot for this project, is situated between two separate Brazilian EEZs, the main continental shelf EEZ, and the one around the islands of Trindade and Martin Vaz. In the year 2004, as it had the right to, Brazil submitted to the Commission on the Limits of the Continental Shelf (CLCS) an extension of its EEZs beyond 200 nautical miles. The term ‘Blue Amazon’ was created to describe this extension to territorial limits specifically to call attention to the immense riches of the oceanic area under Brazilian jurisdiction. In aggregate, the proposal encompasses a maritime area equivalent to more than 50% of the total land area of Brazil (Wiesebron, 2011, 2013).

A concern is that this Blue Amazon submission by Brazil attempts to join its two EEZs, by extending territorial ‘continental shelf’ limits from the Abrolhos Archipelago to Trindade and Martin Vaz, in order to include all the Vitória-Trindade Seamount Chain, including Davis Bank (Fig. 17). This has been requested despite the fact that the raising of these submarine volcanoes is obviously due to a magmatic hotspot and has nothing to do with the continental shelf. The submission was partially rejected by CCLS in April 2007, but Brazil submitted new study papers in April 2015 to try to reverse the original decision (Wiesebron, 2011, 2013). The consideration of this submission was programmed for the 38th session of CLSC from July to September 2015, but as far as we are aware, the resulting recommendations have not yet been published. However, as far as Brazil's hopes for ongoing oil prospecting beyond the existing EEZ is concerned, the section between the continental EEZ and Trindade-Martin Vaz is still preserved.

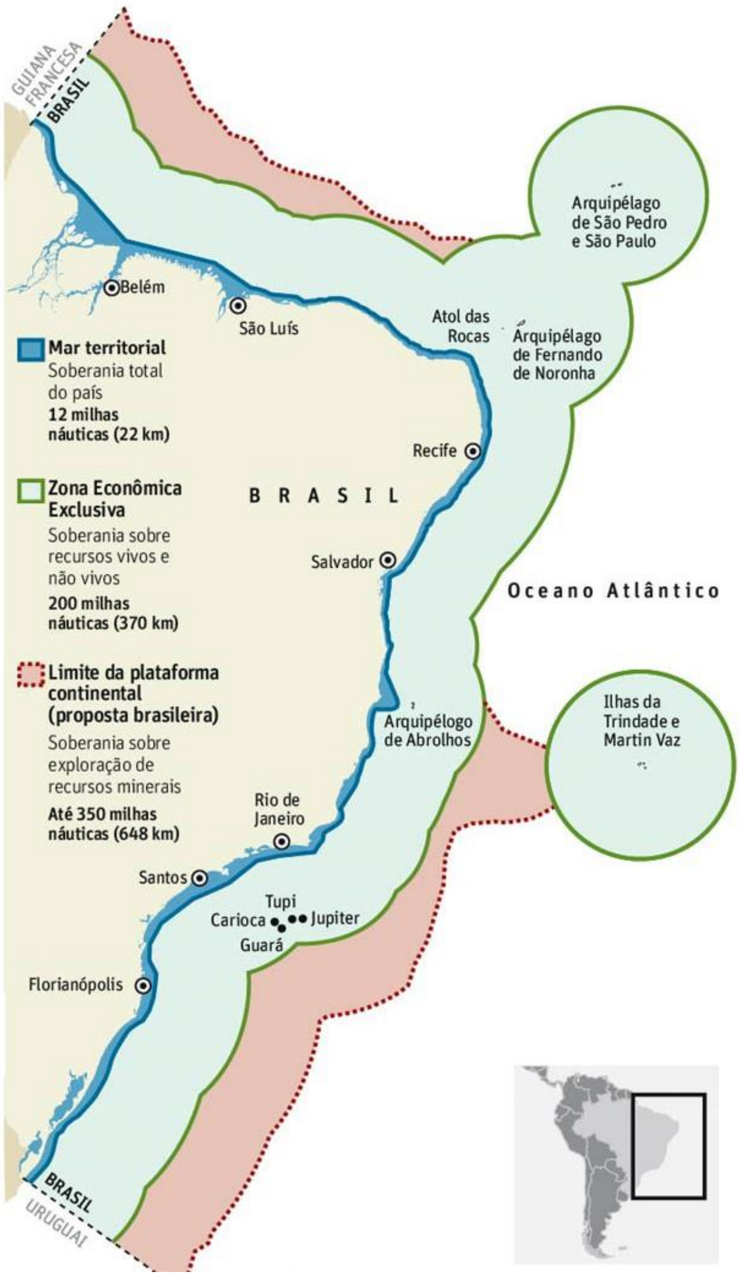


Fig. 17. Map in Portuguese of the proposed limits of the Continental Shelf in order to extend the Exclusive Economic Zone (EEZ) of Brazil. The ***Blue Amazon*** submission by Brazil attempts, among other things, to join its two current EEZs by extending territorial 'continental shelf' limits from the Abrolhos Archipelago to Trindade and Martin Vaz, in order to include all the Vitória-Trindade Seamount Chain, including Davis Bank. Source: la Marine brésilienne at http://f.i.uol.com.br/, via https://commons.wikimedia.org/w/index.php?curid=27752731

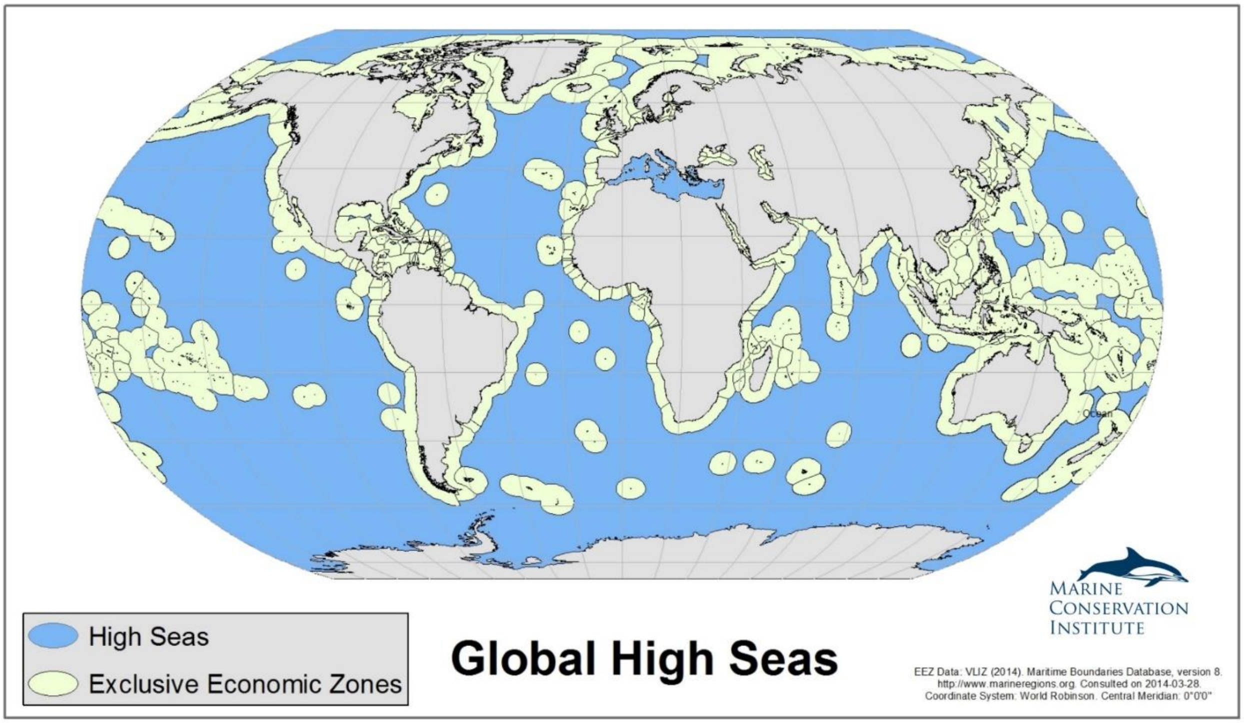


Fig. 18. The ***High Seas*** covers half of the total surface of our planet. Here the High Seas are compared with the world's Exclusive Economic Zones which are subject to the jurisdiction of individual nation states. Source: Marine Conservation Institute (2020), MPAtlas [On-line]. Seattle, WA. Accessed 25 August 2020, URL: http://www.mpatlas.org/data/map-gallery/.

Health of the ecosystems should be placed above politics and business, but we are pragmatic enough to realise that multinational commercial interests control events in this world. Global economic decision-makers could show a little more wisdom and a little less acquisitiveness, but we suppose this is wishful thinking. That is why we believe that only an internationally supported sustainable and profitable business (truly ***healthy*** fish ***farming***), which markets the same product as the wild fisheries around the world, will be able to slow and finally stop today's overfishing. **The better our aquaculture, the less we fish; and let the oceans live**. There is a lot of ocean to manage responsibly for the Common Good. The High Seas cover half of this planet (Fig. 18).

We estimate our project is likely to cost ***about*** one billion US-dollars to make it become a reality, but this is little more than a guestimate. What is clear is that the need for very substantial financial facilities is an inescapable feature. Each simple operation is tremendously expensive on the open sea. It is not the sort of operation that could be started off in a garage, and we lack the personal fortune that would be required for a serious start because this project is not of the sort that could start small and grow. Production would have to begin on a large scale to allow to guarantee this high quality product at an affordable price. Further, it will have to be a philanthropic operation, unlikely to make profits at least until the world's population is nourished properly and the oceans have regained their biological balance.

Today's aquaculture major players have been able to expand thanks to strong capital investments from the likes of the oil industry (Norway), capture fishing industry (Chile) or ship owners (Greece). Perhaps the fish farming industry itself, or its trade associations or common interest groups, like the *Global Salmon Initiative*, could invest in the project. They have the most to gain by developing a sustainable omega-3 rich feed (which does not depend on terrestrial agriculture) to maintain and expand their own sustainable and healthy production of farmed fish.

We think also of all those billionaires, who have decided to give half of their fortune to philanthropy during their lifetime. To date, more than 200 of them have made their commitment within the framework of the Giving Pledge, founded by Bill Gates and Warren Buffet. We are sure that most of them are sincere and not involved in philanthro-capitalism (the 'smart way' to give - for its own interests).

A third perspective is the involvement of UNO itself, to create a supranational food supply, and make a start establishing the Common Heritage of Mankind by initiating a global economy for all of us, and perhaps **the beginning of an universal income**.

8. A dream of a shared Half World

Alongside the production of healthy aquafeed, which is the initial aim of this project and the intended purpose of the high seas infrastructure, the latter is also a wonderful steppingstone to develop other opportunities for sharing industries.

Cosmetics and medicines: Cosmetics containing active agents from marine sources provide some of the most sympathetic interactions with the skin. The market for natural cosmetics is constantly growing and already faces shortages in supplies of uncontaminated ingredients. The understandable tendency for consumers to seek natural ingredients in their cosmetics, no longer allows the industry to artificially reproduce natural molecules they find interesting. To be both accepted and appreciated, ingredients need to be produced naturally in a healthy and sustainable way. Chemically synthesised molecules or even cultures in stainless steel or plastic tanks will not be able to compete with cultures in natural seawater originating from before the Anthropocene (Fig. 19).

Moreover, many chemicals produced by marine organisms are useful as medicines. Manzamine A, for example, a pentacyclic alkaloid with various bioactivities, including recently reported anticancer activity on pancreatic, colorectal and cervical cancer (Lin *et al*., 2018; Karan *et al*., 2020)(Fig. 19). It is produced by a sponge common in Indonesian waters. *Acanthostrongylophora ingens* is able to grow well in poor-quality polluted water, but heavy metals and other contaminants could bind to manzamine A, making it more difficult and expensive to extract. Yet another argument to prefer the pristine waters from the AAIW upwelled with the Perpetual Salt Fountain pipes for cultivation of marine species.

Fishing with dolphins: The oasis of life that could be created on Davis Bank will also result in numerous interactions with wild animals and inspire other challenges. Sea bream, for example, will come and crunch mussels. Dolphins, seals or other marine mammals will also be attracted and could provide the final delights. Indeed, these particular species can be educated, trained, or encouraged to assist capture fishermen by selecting wild fish shoals in their territories using their echolocation and driving the shoals of fish into the fishermen's nets.

There are several places on Earth where dolphins collaborate in hunting fish together with mankind, in Brazil, but also in Mauritania and Myanmar as well. These cooperative and mutually beneficial bonds have lasted for generations, even since the 15th century in Mauritania, and are based on trusting relationships between individuals of the two species who both do well out of it. The cooperation between the bottlenose dolphins and the fishermen of Laguna, Brazil is illustrated in the YouTube video at this URL: https://youtu.be/GjuW6xODzw4.

Combined with the dolphin's ability to recognise geometric figures and colours (demonstrated on a daily basis in marine parks the world over), their goodwill could certainly allow us to herd schools of targeted fish species towards prepared fishing nets around the Davis Bank facility, which would avoid or greatly reduce the almost inevitable 'bycatch', which is the unwanted fish and other marine creatures trapped by commercial fishing nets which are so often thrown back into the sea dead (in Asiatic prawn fisheries the bycatch is currently 95% of the total catch!). We need to change our old hunter habits and imagine new possibilities to take advantage of our oceans and preserve them at the same time.

Carbon sequestration: Another opportunity is to develop a possible atmospheric carbon sequestration sink. This is because bivalve shells are made of carbon dioxide permanently removed from the atmosphere. If the Davis Bank installation produces 200 tons of mussels on long lines per hectare per year (a low production average if the carrying capacity is given), 50% of that harvest will be shell, representing 100 tons of calcium carbonate containing 12% of carbon; that is 12 tons of carbon per hectare per year, being permanently removed each year. In comparison, a forest on land retains only 4 tons of carbon per hectare per year, and only if it is growing.

Fig. 19. Marine sources for cosmetics and, potentially, medicines. **LEFT**: *Dictyopteris membranacea*, herbarium specimen (collected by B. Navez, July 1982 near Villefranche-sur-mer (France), imaged 2010-02-01 (full size = 12 cm). URL: https://commons.wikimedia.org/wiki/. This is a very widely distributed marine alga. Extracts have been shown to have anti-inflammatory, antioxidant and antimicrobial activities (Aoun *et al*. 2010) and have been used in anti-ageing cosmetic formulations. **RIGHT**: *Acanthostrongylophora ingens*, a common sea sponge growing in Indonesian waters produces a chemical called manzamine A, a pentacyclic alkaloid with various bioactivities, including recently reported anticancer activity on pancreatic, colorectal and cervical cancer (Lin *et al*., 2018; Karan *et al*., 2020). Photographed by B.W. Hoeksema, *in situ*, South of Bangka Island, Indonesia. Image taken from http://www.marinespecies.org/porifera/ on the World Porifera Database [http://www.marinespecies.org/index.php] under a Creative Commons Share Alike 4.0 License.

This, and the scientific debate about the relative importance of the different carbon fluxes occurring during shell production are discussed in detail by Moore *et al*. (2021a). It may seem that the amount of carbon sequestered in the shell is less important than that released by the animal's energy metabolism during shell calcification. This is why shellfish cultivation, unlike reforestation, has not been taken into account as a carbon offset in the international carbon trading system first implemented by the Kyoto Protocol and then taken over by the Paris Agreement on a voluntary basis. However, these isolated carbon fluxes must be understood in correlation with other related natural cycles (Fig. 20). The truth is that CO_2 released during the animal's energy metabolism is merely a component of the metabolic carbon cycle (Fig. 21, below) and ***not a net contribution*** to environmental CO_2.

The chemistry involved in the process of shell-making, called marine ***calcification*** or ***biomineralisation***, relies on a set of ionic (or electrolytic) dissociations and associations in water, which are in equilibria governed by local conditions (Fig 20). $CaCO_3$ and CO_2 are produced from calcium and bicarbonate ***ions*** in solution as described by the following scheme:

$$Ca^{2+} + 2HCO_3^- \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

(in words: one divalent calcium ion + two monovalent bicarbonate ions ⇌ calcium carbonate + carbon dioxide + water).

During the calcification (biomineralisation) reaction, the carbon atom from the first bicarbonate ion HCO_3^- is released as a molecule of CO_2 and the carbon atom of the second bicarbonate ion is used for calcium carbonate formation. Other aspects of marine carbonate system chemistry are illustrated in Fig. 20.

Seawater is over-saturated with calcium and its concentration of bicarbonates largely dominates those of carbonates and dissolved free CO_2. In these conditions, the molecule of CO_2 released during the biomineralisation of shells (if it is not used directly by the surrounding phytoplankton for its photosynthesis), will bind with water, forming carbonic acid which will dissociate forming bicarbonate ions and protons that would be available for marine calcifiers to form more calcium carbonate. Alternatively, the carbonic acid can dissociate to form a carbonate ion and two protons. These electrolyte dissociations and associations are illustrated in Fig. 20 and described by these schemes:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$$

(in words: one molecule of carbon dioxide + one molecule of water ⇌ one molecule of carbonic acid ⇌ one hydrogen ion (= proton) + one monovalent bicarbonate ion ⇌ two hydrogen ions + one divalent carbonate ion).

Release of hydrogen ions (protons) will clearly cause acidification of seawater. Acidity of a solution is measured in terms of the pH, a logarithmic scale of the inverse of the concentration of hydrogen ions ($1/[H^+]$). A neutral solution has a pH of 7, strongly acid, a pH of 5, and a strongly alkaline solution, a pH of about 9 [https://en.wikipedia.org/wiki/PH]. The *Encyclopædia Universalis France* states that "… Since the industrial era, the ocean's basic [alkaline] pH has fallen from 8.2 to 8.1. This drop of 0.1 unit corresponds to an ***increase in acidity of about 25%*** [because the scale is logarithmic]…" [https://www.universalis.fr/encyclopedie/acidification-des-oceans/].

The concern with ocean acidification is the fear that formation of calcium carbonate by calcifier organisms will be disturbed. Fitzer *et al*. (2016) have demonstrated significant changes in the hydrated and dehydrated forms of amorphous calcium carbonate in the crystalline layers of mussel (*Mytilus edulis*) shells cultured under acidification conditions. However, there is evidence that, in *Mytilus*, acidification eases the negative effects of increased sea temperatures on biomineralization, suggesting a complex relationship between calcification and the various components of climate change (Knights *et al*., 2020). Adverse effects of present day ocean acidification are clearly seen to impact the viability of symbiotic algae of coral and giant clams, and in those cases, too, are interwoven with elevated temperatures and light levels in relatively shallow tropical waters.

The present levels of elevation of marine CO_2 concentration are more likely to encourage calcification than discourage it due to consequential increase in proton concentration. The calcification process is thought to have originated when large amounts of excess calcium occurred in seawater at the Precambrian-Cambrian boundary, about 550 million years ago. The organisms of the time had already evolved sophisticated mechanisms for maintenance of cellular calcium homeostasis. It is theorised that the environmental calcium excess produced conditions favouring natural selection for calcification in protists and invertebrates as a mechanism to detoxify extracellular Ca^{2+} and avoid intracellular precipitation of phosphate ions. Now the same process appears to be effective at sequestering anthropogenic carbon. This is discussed in a little more detail by Moore (2021).

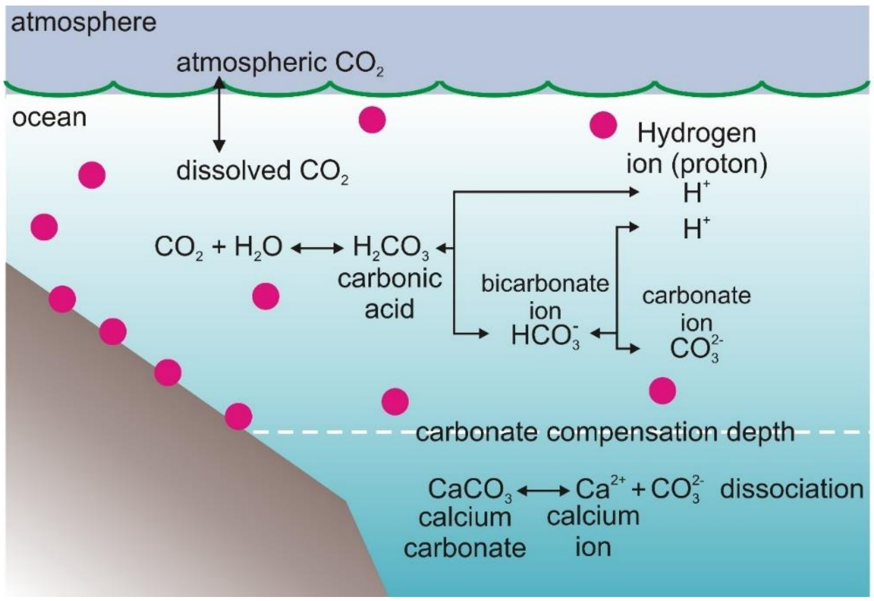


Fig. 20. Summary of the reactions between carbon dioxide (CO_2) with water (H_2O) in the oceans. Calcifying organisms, plant and animal, sessile and floating (represented here by magenta circles) form calcium carbonate ($CaCO_3$) in shallow water, using bicarbonate ions (HCO_3^-) and calcium ions (Ca^{2+}) according to the reversible reaction $2HCO_3^- + Ca^{2+} \leftrightarrow CaCO_3 + H_2O + CO_2$. Today, the calcium ***ion*** concentration, [Ca^{2+}], in the oceans is essentially a function of salinity, and is fairly constant in the ocean. At normal temperatures and pressures the ***salt***, $CaCO_3$, is essentially insoluble in water but solubility increases with pressure and decreases with temperature. In the ocean depths $CaCO_3$ dissolves (and the salt dissociates into $Ca^{2+} + CO_3^{2-}$) below the ***carbonate compensation depth*** (CCD; also known as the carbonate saturation horizon). The CCD varies between 3000 to 5000 m depth in different marine regions (shallower at high latitudes). If the solubilised calcium carbonate is swept to lesser depths it will recrystallise and the crystals will have the opportunity to grow until they reach a size that prompts their sedimentation to the sea floor at those lesser depths. Figure adapted and redrawn after an image in *Encyclopædia Universalis France* [https://www.universalis.fr/media/DE120411/].

Mussel respiration, in its turn, is due to metabolic activities, fuelled by the ingestion of phytoplankton carbon, which belongs to the biological carbon reservoir of the ocean, like all other marine organisms. After a variable residence time there among the prey-predator relationships, only a fraction of this reservoir carbon reaches the sea bottom sediments and is then sequestered for a long time - millennia and more. When phytoplankton is ingested by shellfish, the carbon track is the same as for other plankton eaters but involves only the animal's soft body with its metabolism, not its shell formation. That is why mussel respiration is neutral in this carbon budget.

Shellfish shells, including those of crustacea, are not made of living cells and are produced outside the animal's body. Bivalve shell calcium carbonate is elaborated by the mollusc's mantle using calcium bicarbonate from seawater, the carbon of which originates ultimately from the atmosphere. The important thing is what remains after the animal's death. The shell carbon is effectively and permanently sequestered in a crystalline mineral form, indigestible and ***chemically stable for geological periods of time***.

The same pattern of carbon fluxes occurs with forests. In the same way as the marine phytoplankton, terrestrial green plants are photosynthetic primary producers that fix carbon dioxide out of the atmosphere into their carbohydrates. The carbon reservoir of a forest is represented, of course, by its biomass of wood, leaves, fruit, and roots, but also by all of the animals, large and small, that depend on the plants for food, all of the microbes, bacteria, fungi and protozoa that digest the wastes of the forest, and all of the carbon accumulated over the years in the humus of the forest soil.

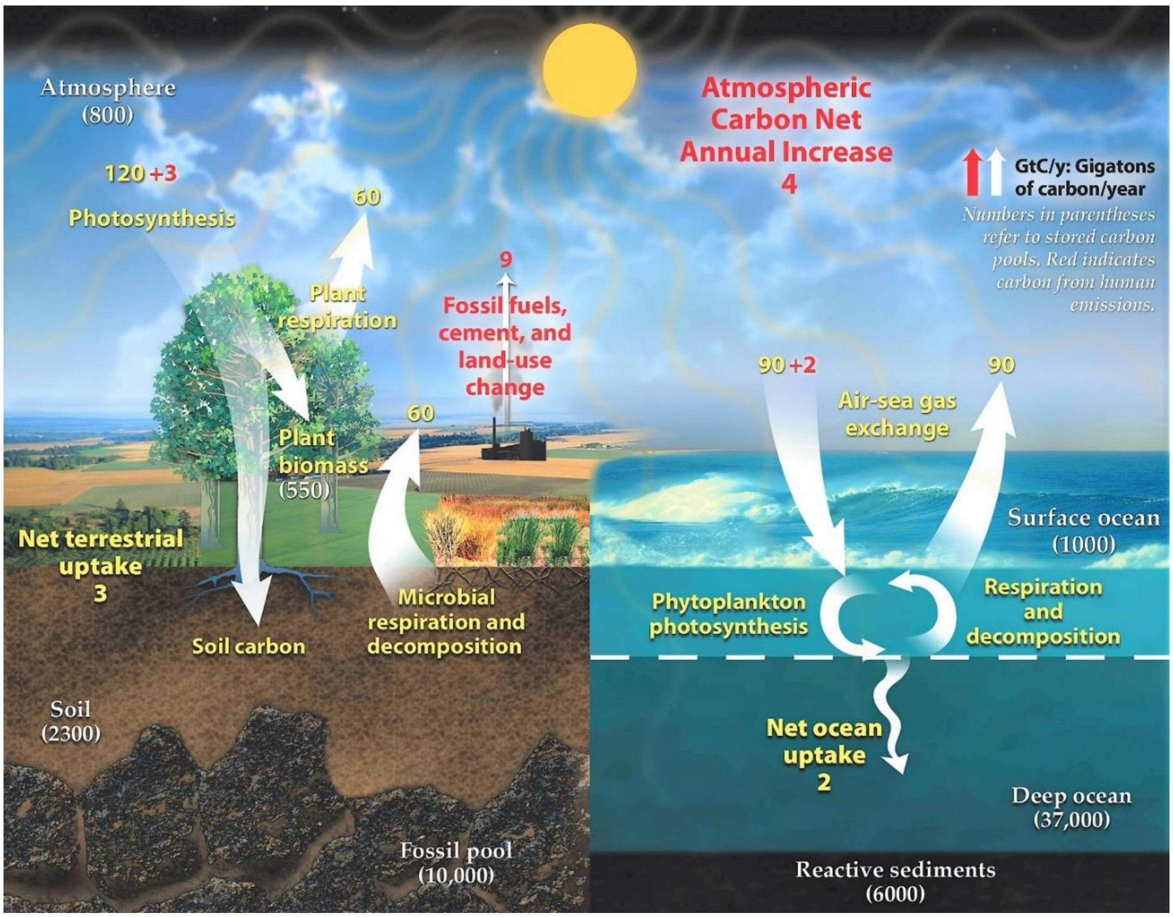


Fig. 21. Movement of carbon between land, atmosphere, and ocean; numerals show amount of carbon in billions of metric tonnes per year (GtC/y). Yellow numbers are natural fluxes, red are human contributions, white are stored carbon. The effects of volcanic and tectonic activity are not included. Image from the Report: US DOE, (2008). *Carbon Cycling and Biosequestration: Report from the March 2008 Workshop*, DOE/SC-108, U.S. Department of Energy Office of Science (https://genomicscience.energy.gov/)(Riebeek, 2011).

The most important point about sequestration of carbon by the forest biome is that it is ***temporary***, because the plants (and the animals they feed) will die all too soon and their subsequent decay releases their carbon back into the atmosphere again. Fig. 21 illustrates the general features of the global carbon cycle. It is enough to say that forests are relevant carbon sinks only as long as they are in active growth. So, forest industries are ***not*** good long-term candidates for the international carbon trade despite the fact that reforestation is believed so widely to be a respected opportunity for industries who need to improve their carbon footprint. **There is a better alternative**.

In contrast to forests, if expansion of shellfish cultivation were to be accepted as a carbon sink within the framework of the carbon trading system, it would be much more sustainable, easier to implement and, most importantly, offer permanent removal of carbon from the atmosphere (Moore *et al*., 2021a & b). It is easier to implement because cultivating a marine species does not challenge the use of scarce agricultural land for conventional terrestrial farming for food. Further, shellfish cultivation can be combined with conservation projects (Moore *et al*., 2021b) and restoration of extinct shellfish fisheries which would tackle the problem of undernourishment around the globe.

Polluting states, cities and industries wishing to improve their carbon footprint, could thus make their contribution to climate mitigation while, at the same time giving a serious boost to conservation of coastal areas and the fight against malnutrition. Instead of paying people to plant trees that still need to be maintained or even watered to grow properly and fulfil their duty of (only) temporarily sequestering carbon, these contributions could fund the research, equipment and teaching required to spread enhanced shellfish cultivation around the globe. The needed workers will then be able to pay themselves with the food they produce and secure their environment permanently, locally as well as globally. Shellfish cultivation ***must*** be taken into account as a carbon offset in the international carbon trading system.

How this project can contribute is that apart from the planned mussel production intended for aquafeed on Davis Bank (which is centred on harvested mussel ***meat***), a carbon sequestration programme (focussed on the mussel ***shell***) could also be deployed easily, and on a massive scale, from this location towards the high seas. Given the large biomass of mussel larvae (each female spawns millions of eggs), it would be feasible to produce quantities of small biodegradable floating devices, to let them collect mussel larvae from the spawning mussels of the Davis Bank facility before being released into the passing Brazil Current (BC) which then carries them south-easterly towards the South Atlantic Gyre.

This idea can also be expanded in an even more scalable way without a fixed installation on Davis Bank (intended for meat production), with several factory ships (intended for shell production), equipped with mussel hatcheries and producing those biodegradable floatation devices, already spawned with fixed juvenile mussels that could be released in all ocean currents and ocean gyres.

In both cases, the shellfish will grow (even in oligotrophic waters where the animal will make proportionately more shell than flesh) and, after a while, will sink under their own weight. When the animals die, the carbon locked in their shells as crystalline calcium carbonate will be sequestered in the ocean's depths, at least until reaching the Carbonate Compensation Depth, or CCD, which is defined as the depth in the oceans below which the solid carbonate crystals dissolve again. As long as the ocean floor lies above the CCD, carbonate particles will accumulate in bottom sediments, but below that depth, there is no net accumulation of crystalline carbonate (Fig. 20).

This effect is due to the influences of pressure, temperature, and seawater composition on the ***solubility*** of $CaCO_3$, not on its stability as a salt. Calcium carbonate is essentially insoluble in sea surface waters at the present time and the CCD varies between 3000 to 5000 m in different marine regions (shallower at high latitudes). If the solubilised calcium carbonate is swept to lesser depths it will recrystallise and the crystals will have the opportunity to grow until they reach a size that prompts their sedimentation to the sea floor at those lesser depths.

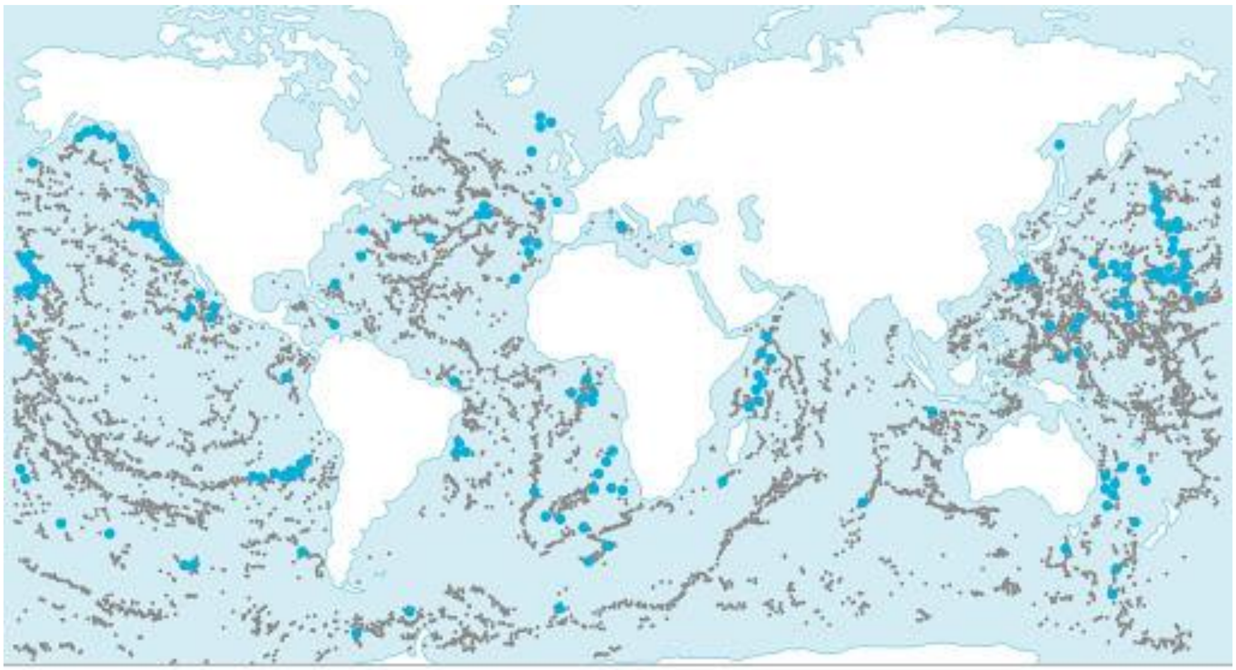


Fig. 22. Global Distribution of seamounts (known seamounts in blue, approximate location of other seamounts in grey). The spatial distribution of seamounts describes where and when seafloor volcanism has occurred in the past. The vast majority of Earth's volcanism occurs on the seafloors and the majority of the seafloor volcanism that forms seamounts occurs in the Pacific Ocean basin. Seamounts are not uniformly, or randomly, distributed in the ocean basins; they are spatially clustered. Most linear chains of seamounts are formed by plates moving over hotspots. Image source: A Planet for Life website http://regardssurlaterre.com/en/node/20004.

Even in the worst circumstances, the carbon sequestered in shellfish shell is permanently removed from the atmosphere. If it enters solution at or below the CCD it will be carried by the global thermohaline circulation and is likely to take a good thousand years to surface again. We can make a start on this carbon sequestration process on Davis Bank because of its ideal environment, but there are many seamounts (and other ocean gyres) awaiting us when the technology has been developed and validated (Fig. 22).

Considering all these arguments, it seems that shellfish farming is the only industry able to scale up massively to provide protection to us ***against climate change***, while ***improving global food supply*** at the same time. The most harmful effect of climate change being the undermining of the ecological basis of food production, this proposal to include shellfish cultivation in the carbon trading system may hit two targets with one bullet and would support at least five of the United Nations Sustainable Development Goals (Fig. 23).

Fig. 23. We support the Sustainable Development Goals of the United Nations.

References

Almeida F. 2006. Ilhas oceânicas brasileiras e suas relações com a tectônica atlântica [The Brazilian oceanic islands and relationships with the Atlantic tectonics]. *Terrae Didatia*. **2**: 3-18. URL: https://www.ppegeo.igc.usp.br/index.php/TED/article/view/8333.

Alves R.J.V. 1998. *Ilha da Trindade & Arquipélago de Martin Vaz: Um Ensaio Geobotânico*. Rio de Janeiro: Serviço de Documentação da Marinha, Brasil. 144 pp. ISBN: 8570470549. URL: https://www.marinha.mil.br/secirm/sites/www.marinha.mil.br.secirm/files/documentos/protrindade/producao/ensaio-geobotanico.pdf.

Aoun Z.B., Said R.B. & Farhat F. 2010. Anti-inflammatory, antioxidant and antimicrobial activities of aqueous and organic extracts from *Dictyopteris membranacea*. *Botanica Marina*. **53**: 259-264. DOI: https://doi.org/10.1515/BOT.2010.027.

Aypa S.M. 1990. Mussel culture. Chapter 4 in: *Selected papers on mollusc culture, Regional Seafarming Resources Atlas: Volume II*, SF/WP/90/2, (ed A. Lovatelli). UNDP/FAO Regional Seafarming Development and Demonstration Project (RAS/90/002), National Inland Fisheries Institute, Kasetsart University Campus, Bangkok, Thailand. URL: http://www.fao.org/3/AB737E/AB737E04.htm.

Bernasconi A.A., Wiest M.M., Lavie C.J., Milani R.V. & Laukkanen J.A. 2020. Effect of omega-3 dosage on cardiovascular outcomes: an updated meta-analysis and meta-regression of interventional trials. *Mayo Clinic Proceedings*. Online ahead of publication. 10 pp. DOI: https://doi.org/10.1016/j.mayocp.2020.08.034.

Berners-Lee M. 2019. *There Is No Planet B: A Handbook for the Make or Break Years*. Paperback, 302 pp. Cambridge University Press: UK. ISBN: 9781108439589.

Bollier D. & Helfrich S. (eds) 2013. *The Wealth of the Commons: a World Beyond Market and State*. 442 pp. Amherst, MA, USA: Levellers Press. ISBN: 978-1937146146. URL: http://wealthofthecommons.org/home.

Escobar-Lux R.H., Fields D.M., Browman H.I., Shema S.D., Bjelland R.M., Agnalt A.-L., Skiftesvik A.B., Samuelsen O.B. & Durif C.M.F. 2019. The effects of hydrogen peroxide on mortality, escape response, and oxygen consumption of *Calanus* spp. *FACETS Journal*. **4**: 626-637. DOI: https://doi.org/10.1139/facets-2019-0011.

Fan W., Zhang Z., Yao Z., Xiao C., Zhang Yao, Zhang Yongyu, Liu J., Di Y., Chen Y. & Pan Y. 2020. A sea trial of enhancing carbon removal from Chinese coastal waters by stimulating seaweed cultivation through artificial upwelling. *Applied Ocean Research*. **101**: article 102260. DOI: https://doi.org/10.1016/j.apor.2020.102260.

FAO, 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Published by the Food and Agriculture Organization of the United Nations, Rome, open access under licence CC BY-NC-SA 3.0 IGO (https://creativecommons.org/licenses/by-nc-sa/3.0/igo). ISBN 9789251326923. URL: www.fao.org/3/ca9229en/ca9229en.pdf.

Filgueira R., Comeau L., Guyondet T., Mckindsey C. & Byron C. 2015. Modelling carrying capacity of bivalve aquaculture: a review of definitions and methods. In: *Encyclopedia of Sustainability Science and Technology*, (ed. R.A. Meyers). New York, USA: Springer Science+Business Media. ISBN: 9781493924936. DOI: https://doi.org/10.1007/978-1-4939-2493-6_945-1.

Fitzer S.C., Chung P., Maccherozzi F., Dhesi S.S., Kamenos N.A., Phoenix V.R. & Cusack M. 2016. Biomineral shell formation under ocean acidification: a shift from order to chaos. *Scientific Reports*, **6**: article number 21076. DOI: https://doi.org/10.1038/srep21076.

Franz D.R. 1993. Allometry of shell and body weight in relation to shore level in the intertidal bivalve *Geukensia demissa* (*Bivalvia: Mytilidae*). *Journal of Experimental Marine Biology and Ecology*. **174**: 193-207. DOI: https://doi.org/10.1016/0022-0981(93)90017-I.

Fuentes-Santos I., Labarta U. & Álvarez-Salgado X.A. 2019. Modelling mussel shell and flesh growth using a dynamic net production approach. *Aquaculture*. **506**: 84-93. DOI: https://doi.org/10.1016/j.aquaculture.2019.03.030.

Gammone M.A., Riccioni G., Parrinello G. & D'Orazio N. 2019. Omega-3 polyunsaturated fatty acids: benefits and endpoints in sport. *Nutrients*. **11**: article number 46. DOI: https://doi.org/10.3390/nu11010046.

Geraldes M.C., Motoki A., Costa A., Mota C.E. & Mohriak W.U. 2013. Geochronology (Ar/Ar and K–Ar) of the South Atlantic post-break-up magmatism. *Geological Society, London, Special Publications*. **369**: 41-74. DOI: https://doi.org/10.1144/SP369.21.

Gimin R., Mohan R., Thinh L.V. & Griffiths A.D. 2004. The relationship of shell dimensions and shell volume to live weight and soft tissue weight in the mangrove clam, *Polymesoda erosa* (Solander, 1786) from northern Australia. *NAGA, WorldFish Center Quarterly*. **27**: Nos. 3 & 4, Jul-Dec 2004. URL: http://www.worldfishcenter.org/Naga/na_2318.pdf.

Helm M.M., Bourne N. & Lovatelli A. 2004. *Hatchery culture of bivalves. A practical manual*. FAO Fisheries Technical Paper. No. 471, pp. 203. Rome: Food and Agriculture Organization of the United Nations. ISBN 9251052247. URL: http://www.fao.org/3/y5720e/y5720e02.htm. PDF: http://aquacultura.org/upload/files/pdf/library/fao/Hatchery%20culture%20of%20bivalves.pdf.

Hilbish T.J. 1986. Growth trajectories of shell and soft tissue in bivalves: seasonal variation in *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology*. **96**: 103-113. DOI: https://doi.org/10.1016/0022-0981(86)90236-4.

Holmgren D. (2011). *Permaculture Principles & Pathways Beyond Sustainability*. 2nd edn. Paperback, 320 pp. Published by: Permanent Publications: Hampshire, UK. ISBN: 978-1856230520.

Karan D., Dubey S., Pirisi L., Nagel A., Pina I., Choo Y.-M. & Hamann M.T 2020. The marine natural product manzamine A inhibits cervical cancer by targeting the SIX1 protein. *Journal of Natural Products*. **83**: 286-295. DOI: https://doi.org/10.1021/acs.jnatprod.9b00577.

Knights A.M., Norton M.J., Lemasson A.J. & Stephen N. 2020. Ocean acidification mitigates the negative effects of increased sea temperatures on the biomineralization and crystalline ultrastructure of *Mytilus*. *Frontiers in Marine Science*. **7**: article 567228. DOI: https://doi.org/10.3389/fmars.2020.567228.

Lin L.-C., Kuo T.-T., Chang H.-Y., Liu W.-S., Hsia S.-M. & Huang T.-C. 2018. Manzamine A exerts anticancer activity against human colorectal cancer cells. *Marine Drugs*. **16**: article 252. DOI: https://doi.org/10.3390/md16080252.

Lovatelli A. 1990. *Artificial propagation of bivalves: techniques and methods*. Technical paper prepared as part of the Mollusc-Shellfish Culture Course of the 7th NACA Training Course for Senior Aquaculturists in Asia and in the Pacific. FAO/UNDP Regional Seafarming Demonstration and Development Project (RAS/90/002) Bangkok, Thailand: National Inland Fisheries Institute, Kasetsart. URL: http://www.fao.org/3/AB739E/AB739E00.htm.

Lubiana K.M.F. & Dias Júnior C. 2016. The composition and new records of micro- and mesophytoplankton near the Vitória-Trindade Seamount Chain. *Biota Neotropica*. **16**: e20160164. DOI: https://doi.org/10.1590/1676-0611-BN-2016-0164.

Maruyama S., Behnia M., Chisaki M., Kogawa T., Okajima J. & Komiya A. 2013. Large eddy simulation of the diffusion process of nutrient-rich up-welled seawater. *Frontiers in Heat and Mass Transfer*. **4**: article 023002. DOI: http://dx.doi.org/10.5098/hmt.v4.2.3002.

Maruyama S., Tsubaki K., Taira K. & Sakai S. 2004. Artificial upwelling of deep seawater using the perpetual salt fountain for cultivation of ocean desert. *Journal of Oceanography*. **60**: 563-568. DOI: https://doi.org/10.1023/B:JOCE.0000038349.56399.09.

Maruyama S., Yabuki T., Sato T., Tsubaki K., Komiya A., Watanabe M., Kawamura H. & Tsukamoto K. 2011. Evidences of increasing primary production in the ocean by Stommel's perpetual salt fountain. *Deep Sea Research* Part I: *Oceanographic Research Papers*. **58**: 567-574. DOI: https://doi.org/10.1016/j.dsr.2011.02.012.

Marza E., Long T., Saiardi A., Sumakovic M., Eimer S., Hall D. H. & Lesa G. M. 2008. Polyunsaturated fatty acids influence synaptojanin localization to regulate synaptic vesicle recycling. *Molecular Biology of the Cell*. **19**: 833–842. DOI: https://doi.org/10.1091/mbc.e07-07-0719.

Mascarenhas V. & Keck T. (2018). Marine optics and ocean color remote sensing. Chapter 4 in: *YOUMARES 8 – Oceans Across Boundaries: Learning from each other*, Proceedings of the 2017 conference for YOUng MARine RESearchers, Kiel, Germany. (ed S. Jungblut, V. Liebich & M. Bode-Dalby). Pp. 41-54. Open access. Switzerland: Springer Nature. ISBN: 978-3030066307. DOI: https://doi.org/10.1007/978-3-319-93284-2_4.

Meirelles P.M., Amado-Filho G.M., Pereira-Filho G.H., Pinheiro H.T., de Moura R.L., Joyeux J.-C., Mazzei E.F. Bastos A.C., Edwards R.A., Dinsdale E., Paranhos R., Santos E.O., Iida T., Gotoh K., Nakamura S., Sawabe T., Rezende C.E., Gadelha Jr. L.M.R., Francini-Filho R.B., Thompson C. & Thompson F.L. 2015. Baseline assessment of mesophotic reefs of the Vitória-Trindade Seamount chain based on water quality, microbial diversity, benthic cover and fish biomass data. *PLoS ONE*. **10**: article e0130084. DOI: https://doi.org/10.1371/journal.pone.0130084.

Milhazes-Cunha H. & Otero A. 2017. Valorisation of aquaculture effluents with microalgae: the Integrated Multi-Trophic Aquaculture concept. *Algal Research*. **24**: 416-424. DOI: https://doi.org/10.1016/j.algal.2016.12.011.

Mohriak W. 2020. Genesis and evolution of the South Atlantic volcanic islands offshore Brazil. *Geo-Marine Letters*. **40**, 1-33. DOI: https://doi.org/10.1007/s00367-019-00631-w.

Moore D. 2020. A biotechnological expansion of shellfish cultivation could permanently remove carbon dioxide from the atmosphere/Una ampliación biotecnológica del cultivo de moluscos bivalvos podría eliminar permanentemente el dióxido de carbono de la atmósfera. *Mexican Journal of Biotechnology*. **5**: 1-10. DOI: https://doi.org/10.29267/mxjb.2020.5.1.1.

Moore D., Heilweck M. & Petros, P. 2021a. Saving the Planet with Appropriate Biotechnology: 1. Diagnosing the Problems/Salvando el planeta con biotecnología apropiada: 1. Diagnóstico de los problemas. *Mexican Journal of Biotechnology*. **6**(1): 1-30. DOI: https://doi.org/10.29267/mxjb.2021.6.1.1.

Moore D., Heilweck M. & Petros, P. 2021b. Saving the Planet with Appropriate Biotechnology: 2. Cultivate Shellfish to Remediate the Atmosphere/Salvando el planeta con biotecnología apropiada: 2. Cultivar mariscos para remediar la atmósfera. *Mexican Journal of Biotechnology.* **6** (1): 31-91. DOI: https://doi.org/10.29267/mxjb.2021.6.1.31.

Motoki A., Motoki K.F. & Melo D.P. 2012. Caracterização da morfológia submarina da cadeia Vitória-Trindade e áreas adjascentes-ES, com base na batimetria preditada do topo versão 14.1 [Submarine morphology characterization of the Vitória-Trindade chain and the adjacent areas, State of Espírito Santo, Brazil, based on the predicted bathymetry of the topo version 14.1]. *Revista Brasileira de Geomorfologia*. **13**: 151-170. URL: http://www.lsie.unb.br/rbg/index.php/.

Olsen Y. 2002. MARICULT Research Programme: background, status and main conclusions. *Hydrobiologia*. **484**: 1-10. DOI: https://doi.org/10.1023/A:1021376517916.

Opsahl-Ferstad H.-G., Rudi H., Ruyter B. & Refstie S. 2003. Biotechnological approaches to modify rapeseed oil composition for applications in aquaculture. *Plant Science*. **165**: 349-357. DOI: https://doi.org/10.1016/S0168-9452(03)00194-8.

Pauly D., Christensen V., Dalsgaard J., Froese R. & Torres F. 1998. Fishing Down Marine Food Webs. *Science*. **279**: 860-863. DOI: https://doi.org/10.1126/science.279.5352.860.

Pinheiro H.T., Mazzei E., Moura R.L., Amado-Filho G.M., Carvalho-Filho A., Braga A.C., Costa P.A.S., Ferreira B.P., Ferreira C.E.L., Floeter S.R., Francini-Filho R.B., Gasparini J.L.,Macieira R.M., Martins A.S., Olavo G., Pimentel C.R., Rocha L.A., Sazima I., Simon T., Teixeira J.B., Xavier L.B. & Joyeux J.-C. 2015. Fish biodiversity of the Vitória-Trindade Seamount Chain, Southwestern Atlantic: an updated database. *PLoS ONE*. **10**: article e0118180. DOI: https://doi.org/10.1371/journal.pone.0118180.

Riebeek H. 2011. *The Carbon Cycle*. NASA: Earth Observatory website. EOS Project Science Office at NASA Goddard Space Flight Center. URL: http://earthobservatory.nasa.gov/.

Ruddiman W.F. 2014. *Earth's Climate: Past and Future*, 3rd edn. 464 pp. W.H. Freeman & Co.: NY, USA. ISBN: 978-1319154004.

Ruyter B., Sissener N., Østbye T., Simon C., Krasnov A., Bou M., Sanden M., Nichols P.D., Lutfi E. & Berge G.M. 2019. N-3 Canola oil effectively replaces fish oil as a new safe dietary source of DHA in feed for juvenile Atlantic salmon. *British Journal of Nutrition*. **122**: 1329-1345. Open source DOI: https://doi.org/10.1017/S0007114519002356.

Scholten H. & Smaal A.C. 1998. Responses of *Mytilus edulis* L. to varying food concentrations: testing EMMY, an ecophysiological model. *Journal of Experimental Marine Biology and Ecology*. **219**: 217-239. DOI: https://doi.org/10.1016/S0022-0981(97)00182-2.

Scholten H. & Smaal A.C. 1999. The ecophysiological response of mussels (*Mytilus edulis*) in mesocosms to a range of inorganic nutrient loads: simulations with the model EMMY. *Aquatic Ecology*. **33**: 83-100. DOI: https://doi.org/10.1023/A:1009995823741.

Seed R. 1968. Factors influencing shell shape in the mussel *Mytilus edulis*. *Journal of the Marine Biological Association of the United Kingdom*. **48**: 561-584. DOI: https://doi.org/10.1017/S0025315400019159.

Seed R. 1980. Shell growth and form in the Bivalvia. In: *Skeletal Growth of Aquatic Organisms: Biological Records of Environmental Change*, (ed D.C. Rhoads). Pp. 23-68. New York: Springer Science+Business Media. 750 pp. ISBN 9780306402593.

Shepard M. 2013. *Restoration Agriculture: Real World Permaculture for Farmers*. Paperback, 339 pp. Published by Acres U.S.A. Inc.: Austin TX, USA. ISBN: 978-1601730350.

Stommel H., Arons A.B. & Blanchard D. 1956. An ocean curiosity: the perpetual salt fountain. *Deep-Sea Research*. **3**: 152–153. DOI: https://doi.org/10.1016/0146-6313(56)90095-8.

Telesca L., Michalek K., Sanders T., Peck L.S., Thyrring J. & Harper E.M. 2018. Blue mussel shell shape plasticity and natural environments: a quantitative approach. *Scientific Reports*. **8**: article 2865. DOI: https://doi.org/10.1038/s41598-018-20122-9.

Utting S.D. & Spencer B.E. 1991. *The hatchery culture of bivalve mollusc larvae and juveniles*. Laboratory Leaflet Number 68. Pp. 32. Lowestoft, UK: Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research. Download PDF URL: https://www.cefas.co.uk/.

Wiesebron M.L. 2011. L’Amazonie bleue et les enjeux et contraintes maritimes du Brésil. *La Revue Défense Nationale*. Revue n° 738: 45-51. URL: https://defnat.fr/.

Wiesebron M.L. 2013. Blue Amazon: thinking the defense of Brazilian maritime territory. *AUSTRAL*: *Brazilian Journal of Strategy & International Relations*. **2**: 101-124. URL: https://seer.ufrgs.br/index.php/austral/article/viewFile/35039/23931.