THE SEAWEED DELUSION

Industrial seaweed will not cool the climate or save nature

etc GROUP

Contents

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Key takeaways

- As the world scrambles for a climate fix, seaweeds – or "macroalgae" – have been thrust into the limelight. Buoyed up by hype and hundreds of millions of dollars of so called "green" investment, a new "blue carbon" seaweed industry is invading coasts and seas, ostensibly under the umbrella of the 2015 Paris Agreement on Climate Change.

- By mid-2023 there were more than 1,300 companies involved in commercial seaweed, including more than 200 start-ups. Many of these start-ups are led by individuals from the software, finance, engineering and media industries with no prior experience in aquaculture, seaweed ecology, seaweed gathering or mariculture, who see new profit-making opportunities on the horizon.

- Under close scrutiny, most of the arguments being used to promote these "blue carbon" seaweed projects – which include industrial-scale farming and sinking seaweed, through to "rewilding" and restoration projects – fail to stack up. For example, it has been found that seaweed ecosystems can be carbon sources rather than sinks – potentially causing up to 150 tonnes of CO_2 emissions/km²/year.

- Indigenous Peoples, traditional communities and fisherfolk reliant on coastal ecosystems would be severely impacted by industrial seaweed scaleup plans. One study suggests that to sequester just 0.2% of global CO_2 emissions would require an ocean seaweed farm equivalent to a 100-meter-wide belt around 63% of the world's coastline. This would be an unprecedented occupation of coastal territories, causing displacement and eroding vital food systems and livelihoods.

- Deep sea options are no better. The race to sink seaweed in the ocean has been described by one group of scientists as "outpacing the rate of progress of the essential science to assess risks, surging past even perfunctory evaluation of the environmental impacts and social benefits." Mass seaweed sinking is surrounded with uncertainties about impacts on life at the seafloor.

- Options such as industrial-scale kelp farming are also being heavily promoted even though they will take all the already-known problems associated with terrestrial tree monocultures to the seas – threatening marine and coastal species, including wild seaweeds, biodiversity and ecosystems, facilitating the spread of pathogens, driving resource grabs and displacing traditional communities.

- Natural and traditionally-managed seaweed ecosystems are among the most biologically productive areas in nature, helping to generate a significant amount of global oxygen and reduce ocean acidification, providing habitats for many other organisms and feeding the ocean food chain. They are a key element of sustainable food security and a crucial basis for many peasant and Indigenous livelihoods.

- It is therefore of the utmost importance that the "Seaweed Commons" are recognized and protected! The livelihoods, cultural and traditional practices of seaweed gatherers, Indigenous Peoples and coastal communities where seaweed is a keystone cultural species must be prioritized, recognized and protected. It is time to act to protect seaweed as a traditional livelihood and a commons for present and future generations.

- To this end, the UN and governments must affirm the need for precaution, and act urgently to stop seaweed industrial farming and sinking, including by prohibiting its licensing and expansion, and banning the release of genetically modified seaweed or other GM organisms in seaweed- and related ecosystems. Clearly, industrial seaweed farming and sinking must also be excluded from the discussions on new carbon market mechanisms under the UNFCCC's Paris Agreement (Article 6).

Overview

Seaweed "revolution"? As the world scrambles for a climate fix, seaweeds such as kelp – also called "macroalgae" – have been thrust into the limelight. Buoyed up by hype and hundreds of millions of dollars of investment in the wake of the 2015 Paris Agreement on Climate Change, industrial seaweed is the latest "green" invasion with hundreds of start-ups promising to grow, harvest, transform (and, in some ventures, sink) up to 500 million tonnes of seaweed biomass[1] and to restore underwater kelp forests. Some even claim they will suck a trillion tonnes of CO_2 out of the air in the process.[2]

According to commercial proponents, macroalgae have the triple benefit of being fast growing, widely scalable and able to store carbon in a deep ocean locker. Several business plans describe sequestering carbon dioxide this way: geoengineering startups – many with funds from Elon Musk, Microsoft and Amazon's Jeff Bezos – plan to earn carbon credits from high-tech robotic seaweed-growing in the open ocean or by dumping large amounts of algal biomass at sea. Some entrepreneurs hope to establish large monoculture plantations of kelp along coasts. Others hope to sweep up floating Sargassum by drone submarine. Others claim that high volumes of seaweed used as cattle feed, fertilizer and alternative protein will displace fossil fuels and cut methane emissions.

...Or seaweed delusion? As with previous technofix hypes, the simple salty stories told to investors and governments fall apart under scrutiny. Traditional seaweed gatherers and Indigenous Peoples who have known seaweeds intimately for centuries point out that algal species are part of local cultures and have been helping "save the planet" long before Silicon Valley investors appeared on the horizon.[3] They warn that, just as tree monoculture plantations are completely different from natural forests, industrial, monoculture seaweed farming is nothing like the artisanal gathering of seaweed. Instead, it will introduce new risks to already stressed marine ecosystems and would threaten small-scale algae cultivators' livelihoods.

Potential ecological impacts include shading the seabed, seagrasses and natural algae, altering local ocean currents, contaminating genetic diversity, and robbing nutrients from plankton and pre-existing marine communities. Evidence from existing industrial seaweed farming in China is not encouraging: seaweeds that have been traced to Chinese aquaculture farms[4] have created the largest harmful ocean algal bloom on earth as apocalyptic-looking green tides inundate beaches in the Southern Yellow Sea every summer and starve water of oxygen – a stark warning that the fragile balance of marine ecosystems is easily upset.

Most significantly, new science suggests that the key claim of industrial seaweed proponents – that seaweed can draw down a lot of atmospheric carbon – is, at best, a grossly overblown claim and furthermore too expensive to be cost-effective. At worst, it could be a new disaster for ecosystems and efforts to combat climate change. Once the math is done, it appears that industrial seaweed ecosystems may actually be net emitters of CO_2. Increasing industrial seaweed acres could therefore lead to *more* CO_2 in the atmosphere, not less.

Some seaweed scale-up proponents are now toning down their climate-saving rhetoric, but ramping up a different – but also unproven – promise instead: that they will rescue ocean biodiversity. They are hoping that the new Kunming-Montreal Global Biodiversity Framework (KMGBF) will unleash biodiversity financing (and future biodiversity credits) in addition to the climate finance that has already flowed into seaweed industrialization.

We've been here before with previous cycles of misplaced and ultimately damaging hype about technofixes such as biofuels, "clean coal" and other false "solutions" to food, climate and biodiversity crises. As it becomes clearer that seaweed is not a climate fix, this is a key moment for environmental policymakers to prevent further damage. Heeding both independent science and warnings from seaweed gatherers and Indigenous Peoples, it is time to put a halt to the seaweed bandwagon and instead ensure that the world's precious natural seaweed and its associated Seaweed Commons are properly protected.

Box 1: About seaweed-based ecosystems

Wild seaweed and artisanal seaweed cultivation provide multiple ecosystem functions that help maintain healthy marine and human communities.

Seaweed-based ecosystems:

- Are among the most biologically productive areas in nature, similar to forests
- Help generate 50-80% of global oxygen (along with phytoplankton and marine plants)
- Help reduce ocean acidification
- Provide nurseries and habitats for many organisms
- Feed the ocean food chain
- Shelter species from predators and water turbulence
- Stabilize sediment, slow storms, reduce wave pressure on beaches and protect vulnerable coastlines
- Cycle nutrients, mitigating nutrient runoff by absorbing phosphate and nitrogen
- Filter heavy metals and other toxicants in the water
- Produce carbonates that build up dunes and beaches
- Influence coastal cloud formation and weather[5]

Photo: Pahala Basuki, Unsplash.

Photo: Seaweed farming. Ron de Boom, flickr.

Artisanal seaweed cultivators work with these natural cycles, and as with forests, usually increase their biodiversity. So, besides their many important ecosystem functions, these ecosystems are also a source of livelihoods for coastal communities, especially women.

Box 2: The Seaweed Commons – a manifesto for precaution and traditional use

While "big seaweed" is calling for billions of dollars of investment into seaweed industrialization, a very different vision of small-scale seaweed stewardship comes from a network called the Seaweed Commons. Describing themselves as an international collective of seaweed growers, lifelong harvesters, scientists and advocates, the Seaweed Commons network argues that seaweed-related developments should be guided by precaution and considerations about conservation and sustenance of livelihoods, and kept to an appropriate scale with local ownership and democratic control prioritized.

In a position statement written to warn against the current seaweed industrialization rush, the Seaweed Commons network points out how rapid scale-up can have "far-reaching detrimental effects on both the environment and the socio-economic health of communities" as well as enabling corporate monopolies. They advocate for more research into the impacts of seaweed industrialization, strong regulatory frameworks supporting Indigenous and ecological communities, small-scale growing and artisanal gathering practices. Their position paper is signed by a variety of ocean, food and seaweed leaders, mainly from North America and Europe – including Indigenous seaweed harvesters, well known chefs and ocean policy experts. The Seaweed Commons position statement can be read at www.seaweedcommons.org

Introduction

Seaweed is a common name that includes a diversity of species of marine organisms, including rockweed, wracks, kelps, dulse, Sargassum, sea tangle and others. There are also estuarine and freshwater algae types, but in this paper we refer specifically to those occurring in the sea.

Seaweed is often also called "macroalgae" indicating that it is neither a land-plant nor what we would normally call just "algae". Rather it refers to some 11,000 different species of large plant-like sea organisms,[6] which can use their entire bodies to photosynthesize. Seaweeds are either red, brown or green and are usually found hugging shorelines or sea floors at less than 100 meters depth. Recent mapping estimates that underwater kelp forests alone cover an undersea area comparable to the Amazon rainforest basin, or twice the size of India.[7]

Seaweeds have long held economic and social importance across many cultures. Peasants, coastal communities and Indigenous communities collect seaweed as fertilizer, medicine and food, and continue to integrate seaweed into traditional practices and ceremonies. Because of its significance and beauty, Chinese emperors wore images of seaweed on their robes.[8]

Commercial farming of seaweeds on lines of rope in the water emerged as an industry in Asia from the 1950s onward. The sector grew 1,000 fold in seventy years, but most of that growth occurred between 2010 and 2020, when it doubled, spurred by its industrial uses.[9] Today, ten species are farmed intensively in 50 countries with 98% of that production still in Asia (half of all production is in China).[10] By 2019, 35.8 million wet tonnes of seaweed were being farmed and exported into a global commercial seaweed market reported as being worth US$15 billion in 2021 (but expected to grow to US$25 billion by 2028).[11] The UN's Food and Agriculture Organization (FAO) claims that farmed seaweed is the fastest-growing food-production sector.[12] It accounts for more than half (51.3%) of global total marine aquaculture by weight.[13]

Most of this farmed commercial seaweed is processed into "algal colloids" such as carrageenan and agar and used in beauty products and processed foods. Seaweeds are also growing in popularity as a direct foodstuff and for use as livestock feed, mulches and compost. Bioprospectors estimate that more than 3,000 marine natural products (MNPs) or bioactive molecules that can be extracted from seaweeds have been found,[14] although relatively few have been commercialized. During the oil crisis of the 1970s, and briefly again in the early 2010s, hopes ran high with respect to turning seaweed into biofuels, but the seaweed biofuel bubble burst both times because the economics didn't add up.[15]

Significantly, as has happened with other internationally traded significant food sources, today's seaweed industry is now dominated by agribusiness traders and ingredients giants such as Cargill, Kerry Group, FMC and DowDuPont.[16]

The Hustle

The big salty promise of carbon and biodiversity finance

> "For generations, seaweed has remained one of the great untapped resources. But a revolution is coming. The seaweed industry is on the cusp of transformation."
> – Seaweed Revolution manifesto, supported by The Global Seaweed Coalition (industry coalition)[17]

The signing of the 2015 UN Framework Convention on Climate Change (UNFCCC) Paris Agreement on Climate Change spurred the idea among profit makers that seaweed could be an effective means of carbon sequestration which could lead to a new carbon market. This led to the seaweed industry experiencing significant growth and a change in character and purpose that some in the industry dubbed "the Seaweed Revolution". By 2019, a new so-called "green" industrial seaweed rush had emerged, driven by the assumption that seaweed farming could help sequester atmospheric carbon dioxide to meet the CO_2 reduction pledges made by political and corporate leaders.

The Paris Agreement stated that it aims to achieve a balance between emissions and sinks of greenhouse gases from the atmosphere. Thus the idea of enhancing natural "sinks" (systems that could absorb and permanently store CO_2 from the air) moved to the forefront of the global climate agenda, offering dirty fossil fuel industries and related sectors a way out of real emissions reductions. Nations who signed the Paris Agreement were expected to draw up national plans to which they would be held accountable, and a rush of large corporations, municipalities, and others pledged to become "net zero". This meant that instead of real emissions reductions they would continue emitting but would "offset" their emissions by removing CO_2 from the atmosphere. As of July 2023, 942 of the world's top 2,000 publicly-traded companies have either pledged to achieve net zero by some point in the future or they are engaged in working out a "corporate strategy" to get there.[18]

In the hustle to meet carbon-reduction commitments, approaches that exploit biological mechanisms have been aggressively promoted under new terms that disguise their industrial nature, such as the term "Nature-Based Solutions" (NBS). It quickly became apparent that the biophysical potential for terrestrial forests alone to sequester additional CO_2 was limited,[19] and increasing attention turned to oceans, prairies and farm soils. Thus the idea of "blue carbon" moved into the climate action playbook. This refers to carbon absorbed and stored – for an uncertain period – by marine and coastal ecosystems.

Many "blue carbon" projects focus on restoring mangroves or seagrasses, and big conservation groups and consultants have also been pushing to include seaweeds as "blue carbon".[20] This has led to the financing of seaweed-related projects as "climate projects" by some governments and private financiers, in the hope that they will become eligible for carbon credits. Alongside this is a growing industry of certifiers, verifiers, offset marketplaces and seaweed trade groups.

At the end of 2021, countries agreed to establish a new mechanism to set the basis for a carbon market under Article 6.4 of the Paris Agreement. A few months later, they began a process to determine eligible sources and techniques that could generate credits for carbon "removals", including several marine geoengineering proposals.[21] This process created the potential for economic incentives to drive a rapid scaling-up of so-called Carbon Dioxide Removal techniques (CDR) (a term for the subset of geoengineering proposals that involve removing carbon from the atmosphere).

Geoengineering refers to the large-scale and intentional technological manipulation of the climate. While some geoengineers hope to revive large ocean schemes to grow microalgae (i.e. ocean fertilization), these are under a global moratorium in the UN Convention on Biodiversity and the London Convention/London Protocol on marine dumping.[22] An additional concern in relation to approving seaweed (macroalgae) for CDR is that it may also be seen as a political "latch lifter" leading towards a relaxation of these precautionary restrictions. Indeed, some key players behind the new seaweed rush are also ocean fertilization advocates (see section on geoengineers below).

In 2022, another global agreement was reached under the UN Convention on Biological Diversity (CBD): the Kunming-Montreal Global Biodiversity Framework. This agreement includes provisions towards establishing additional (yet to be developed) biodiversity credits and other forms of financializing nature.[23] This could also further turbo-charge investment in the seaweed sector. Such financialization is strongly opposed by groups concerned with environmental justice and indigenous and community rights.[24]

The Myths

Five wrong assumptions about seaweed

The seaweed industry's push to develop huge monocultures of industrial algae cultivation and develop new markets for carbon and biodiversity credits are based on a number of myths.

MYTH 1:

Seaweed is a significant carbon sink

No it isn't. The assumption that seaweeds act as a significant carbon sink has been the single most powerful factor driving industrial expansion of seaweed since 2015 and it appears to be wrong. In fact, seaweed ecosystems appear to be a carbon source.

Seaweed does absorb carbon dioxide as it grows, but it also releases carbon back into the water and to the environment when it decomposes or is eaten. Only a small part of seaweed biomass is added to ocean sediments, and even that can only be considered truly sequestered if it remains there permanently, which is uncertain.[25] One study suggests that to sequester as little as one-tenth of a gigatonne of CO_2 annually (which amounts to only 0.2% of global emissions) would require an ocean seaweed farm larger than the country of Ireland or a 100-meter wide belt around 63% of global coastline.[26]

Recent measurements of carbon in sediments under 20 seaweed farms across the globe show that in reality there is a wide variation in the levels of carbon stored on the seabed beneath them.[27] In a quarter of the sample sites, no or negligible carbon sequestration was measured; and the carbon that was measured at the remaining sites could not definitively be attributed to deposition by seaweed growing above. The most optimistic interpretation of the data suggests one hectare of seaweed – growing in the right place and in the right way – may sequester somewhere between 1.06 and 8.10 tonnes of CO_2 per year[28] – that's in the range of the average annual emissions of one passenger vehicle in the U.S.[29] And the estimates for seaweed's sequestration capacity exclude industrial lifecycle carbon emissions from growing, harvesting, drying, processing and transporting seaweed.

Further significant data come from a landmark study by John Barry Gallagher, Victor Shelamoff and Cayne Layton, which considers the role of seaweed in carbon sequestration more comprehensively, effectively debunking (and even reversing) the assumption that seaweed is a significant carbon sink.[30] Gallagher *et al.* show that while seaweed plants may fix carbon dioxide and drop some of that into sediments, seaweed ecosystems appear to be net producers of CO_2 overall. The authors explain that because seaweed ecosystems such as kelp forests attract and nurture many forms of aquatic life, it is necessary to consider the carbon balance of the entire ecosystem, not just of the macroalgae. In summarizing the research, Gallagher explains "Seaweed ecosystems, we found, were natural carbon sources, releasing on average around 20 tonnes per square kilometre every year. But it could be much higher still. When we included estimates of how much carbon returned to the atmosphere from seaweed washed out towards the deep sea only to decompose or be eaten first, we found seaweed could be a much larger natural source [of carbon]. We estimate it could be potentially as high as 150 tonnes emitted to the atmosphere per km² every year."[31] Again those estimates don't take into account carbon emissions from harvesting, drying, transport and processing of farmed seaweed.

Another study that focused on Sargassum came to similar conclusions, documenting that seaweed reduces carbon fixation carried out by plankton in the water.[32] The study also drew attention to microscopic creatures associated with seaweed that generate a process of calcification, emitting atmospheric CO_2 as they do so. This process of calcification lowers the alkalinity of seawater making it less able to absorb CO_2 from the atmosphere. Again, researchers concluded that Sargassum ecosystems were likely a net source of CO_2 emissions or, at best, marginal in their ability to sequester carbon. Finally, the authors posit that marine biota should not be the focus of carbon dioxide removal proposals due to the "inherent complexity of biological systems".[33]

Gallagher and his colleagues didn't mince words about the significance of their findings: "If we get this wrong, we could see perverse outcomes where industries offset their emissions by funding the preservation or restoration of seaweeds – but in doing so, actually increase their emissions rather than zero them out".[34] A 2023 meta-review of more than 180 scientific studies concluded: "we found very little evidence of [seaweed] farms being able to directly contribute to long-term carbon sequestration in the context of an *in situ* farm".[35]

"When we included estimates of how much carbon returned to the atmosphere from seaweed washed out towards the deep sea only to decompose or be eaten first, we found seaweed could be a much larger natural source [of carbon]. We estimate it could be potentially as high as 150 tonnes emitted to the atmosphere per km² every year."

"If we get this wrong, we could see perverse outcomes where industries offset their emissions by funding the preservation or restoration of seaweeds – but in doing so, actually increase their emissions rather than zero them out." [36]

MYTH 2:

Seaweed scale-up is good for marine ecosystems

No, not necessarily. While the ecological functions of natural seaweed are well understood, there is limited evidence to support the planet-saving claims being made about industrially farmed seaweed. Elizabeth Cottier-Cook of The Scottish Association for Marine Sciences (SAMS) reported a lack of hard evidence to back up claims of ecosystem-wide benefits of industrial seaweed farming, despite a survey of over 20 experts and reviewing almost 300 research papers.[37]

Scaling up seaweed production to industrial levels may in fact have negative effects on ecosystems, some of which have already been observed in established Chinese seaweed farms.[38] Here are eight ways that seaweed industrialization can threaten ecosystems:

- **Impacting existing coastal habitats of seagrasses, maerl (coral-like algae) and kelp**
  Given the intensity and scale of industrial seaweed farms, their operations could harm existing coastal habitats, including natural seagrasses, maerl and kelp. Negative impacts could flow from uprooting of seagrass, the placement of farms on top of seagrass and kelp beds, and the shading of light from the seabed affecting natural biological communities or corals. Biomass from the farmed seaweed may smother existing biological communities, and the presence of structures and industrial activities could disrupt marine animal migrations and feeding grounds.[39] In Maine, USA, for example, concerns have been raised about marine mammals, including the endangered North Atlantic Right Whale, getting entangled in kelp lines and nets.[40]

- **Changing the movement of water and ecological connectivity**
  Intensive seaweed farming can alter coastal hydrodynamics (how water moves) by building up sedimentation and slowing down the flow of water.[41] This, combined with floating platforms, can slow or redirect waves, affecting light levels, coastal ecosystems and erosion. Erecting seaweed mariculture facilities resulting in changes in water and the seabed could also disrupt ecological connectivity for marine species[42] (that is, the extent to which spatially distinct populations, communities, ecosystems or habitats are linked by the exchange of genes, organisms, nutrients and energy).[43]

- **Diverting nutrients from microalgae, harming corals**
  To track the impact of a new organism in an environment, it's crucial to monitor the organisms it displaces and competes with. For macroalgae, this means looking out for changes in microalgae populations (e.g. plankton), which could have negative effects on the local food chain. Additionally, scientists warn about the potential for allelopathy, where seaweeds produce compounds that can harm other organisms such as coral.[44]

- **Changes to water: loss of oxygen, increased production of methane and dissolved carbon**
  Algae are important in relation to various gases. In particular, they are the largest global source of oxygen, so displacing microalgae with macroalgae needs to be monitored due to potential impacts on oxygen levels in the water. Increasing amounts of seaweed decomposing in the water could also lead to lower oxygen concentrations (hypoxia) and increased release of methane from the ocean floor.[45] Furthermore, increased seaweed amounts could lead to higher dissolved organic carbon (DOC) levels in the water, which may impact offshore biological communities, including poorly understood microscopic communities.

- **Escapes, invasiveness, algal blooms and pests**
  Approximately 280 seaweed species have been introduced into non-native marine environments.[46] Cultivated seaweeds growing in open ocean environments can easily escape and persist in the wild. They may invade natural seaweed ecosystems, outcompete native seaweed, or cause other ecological harms. This problem has been known for some time, with examples including the Asian red *Kappaphycus* seaweed species that have smothered and killed coral reefs in Hawaii since their introduction for experimental seaweed farming in the 1970s.[47] A dramatic example of harmful algal blooms occurs in China's Yellow Sea where the world's largest bloom of wild seaweed now occurs annually. These blooms began in 2008 after spores and offshoots from the commercial growing of Nori seaweed escaped, reproduced and thrived, including being fed by fertilizer runoff. By 2021, the annual floating seaweed bloom covered 1,746 square kilometres (larger than the city of Montreal).[48] Stark images of families bathing in green slicks of Nori in Qingdao have since traveled the world.[49] These nori-slicks block sunlight and air from entering the ocean, deplete oxygen levels and suffocate marine life. Seaweed farming can also become a vector for novel pests and invasive species, with examples such as the *Lacuna vincta* snail in Maine.[50] A recent overview of seaweed pests concluded that "intensive culture of macroalgae favors more frequent and damaging disease outbreaks", noting that these routinely result in losses of 15–30% of volume in some Asian seaweed harvests; they can also spread to and threaten wild populations.[51]

- **Contamination and loss of genetic diversity**
  Wild seaweed gatherers are concerned about the impact of monoculture farming on natural populations of macroalgae if genes flow to those wild populations. Industrial seaweed farmers prioritize genetic uniformity and biomass growth, which may harm natural diversity. Rules in British Columbia restrict the use of non-native kelp for farming[52] but don't account for genetic diversity even between closely-situated populations of the same species. The experience from China suggests that cross-fertilization between wild and farmed seaweed is common and leads to declining genetic diversity and weaker seaweeds.[53]

- **Contamination with genetically manipulated algae**
  Alarmingly, some seaweed industrialists are also proposing more industrial breeding and genetic engineering strategies to make seaweed "climate-ready" and increase biomass production. For example, there are already gene-edited kelp species in the lab as well as the use of new genetic "priming" techniques.[54] Deliberately altering seaweed genetics this way is a hugely experimental and risky new frontier for a kingdom of mostly undomesticated organisms. Unlike with agricultural crops, there is no history of "seaweed strain breeding", and altering genomes in a species that so freely escapes and crossbreeds raises serious biosafety risks and potential ecosystems risks.

- **Changing weather and local climate**
  Many algae, including some seaweeds, can produce airborne substances that can alter weather. For example, red seaweeds emit bromoform, which thickens clouds and impacts ozone.[55] Northern green seaweeds can produce a compound known as DMSP (dimethylsulfoniopropionate) under stress, which breaks down into DMS (dimethyl sulfide) and acrylic acid to deter herbivores;[56] when released into the atmosphere, DMS affects the formation of clouds.[57] Macroalgae can also emit various halocarbons, which have an effect on ozone.[58]

MYTH 3:

Seaweed is 'fast biomass'

Well, not so fast actually. Seaweed's incredible growth rate is frequently cited by industrialists, with common claims that macroalgae can grow up to 2-3 feet per day.[59] While some species of Pacific bull kelp have been recorded as growing two feet per day during certain times of the year, under ideal conditions,[60] it is not accurate to present this as an *average daily growth* rate for most seaweed species (or even for bull kelp). Using exceptional growth rates from a single species in ideal conditions to make generalized claims about the seaweed industry's potential overall is highly problematic. This can lead to wildly incorrect calculations and specious – or at least faulty – business plans.

"We need to inject a bit of realism into this conversation…I spend a lot of time working with ocean planners -- people that decide on how we use ocean space and, actually, our EEZs [exclusive economic zones] are completely packed with human activities. It's difficult to allocate new space to new activities." - Dr Ana Queirós, Plymouth Marine Laboratory, UK.[61]

MYTH 4:

There is plenty of spare ocean

No–there isn't.

Carbon financiers are attracted to the ocean for its vast size and perceived untapped potential. However, the reality is that the areas most suitable for seaweed farming, particularly coastal regions, are not empty and have cultural and historical significance, as well as often being the basis for the traditional livelihoods of coastal communities. Management authorities engage in "Marine Spatial Planning" to balance the growing demand for industrial development and conservation efforts. As noted, seaweed farms would need to occupy a significant portion of global coastlines to claim even a small impact on reducing greenhouse emissions. Coastal zones have high biodiversity and are subject to pollution and conflicts over rights and access. Additionally, there are many proposals for ocean and coastal activities, including hydrocarbon and mineral extraction, tourism and military activities. These pressures have been referred to as the "blue acceleration."[62]

Photo: Seaweed farmers, Indonesia. Hiswaty Hafid, USAID Biodiversity & Forestry, flickr.

MYTH 5:

Seaweed industrialization is good for coastal communities

No, there is a wide range of social, economic and cultural impacts.

Seaweed cultivation has been promoted as a promising industry that can provide economic benefits to coastal communities by creating jobs and supporting livelihoods. However, claims by the World Bank that the industry could ultimately create 100 million jobs[63] are unrealistic and based on extrapolating from a past situation where seaweed was mostly gathered by hand or cultivated at a small scale. Today's seaweed investors and entrepreneurs envision large, efficient facilities that rely on new technologies, such as autonomous and robotic harvesting systems, which require little human tending. If seaweed transitions to an intensive biomass industry, labor needs will be reduced to remain competitive.

Furthermore, traditional seaweed farming is embedded within complex social-ecological systems, and the social and economic impacts of scaling up seaweed production may be larger and more thorny than industrial seaweed advocates think. While there is evidence that traditional seaweed farming has often improved income and livelihood opportunities, studies have overwhelmingly focused on small-scale production in the South, and it is unlikely that these benefits would extend to larger, industrialized seaweed farming. A recent meta-study of seaweed impacts warned that "in places where seaweed farming adoption has been rapid or heavily industrialized, family farming traditions and community management has decreased in lieu of privatized, fixed location farming that has weakened social cohesion and led to population displacement,"[64] causing loss of livelihoods. Small farmers in poorer countries risk losing control of their coastal areas and traditional algae cultivation livelihoods. Instead they may find themselves trapped in inequitable supply chains, and increasingly vulnerable as global commodity prices fluctuate. They may even struggle to negotiate decent wages. Moreover, rapid industrialization could lead to a loss of traditional community norms that have previously been key to maintaining the sustainable use of local marine resources.

Seaweed post-Paris

The CDR seaweed "elevator pitch"

As explained in the myths section, it is unlikely that seaweed projects will work as CDR (carbon dioxide removal) schemes. Many industrial seaweed companies nonetheless make this claim based on three common but erroneous talking points (which are all based on the myths outlined above):

Speed: "Seaweed is fast growing": For example, giant kelp can grow 2-3 feet in a day.[66]

Scale: "Seaweed scales up": The ocean covers over 70% of the planet's surface. Seaweed proponents promise "basin-scale" operations.[67]

Sequestration: "Seaweed fixes CO_2 in biomass": Researchers have estimated that macroalgae may sequester about 173 million metric tonnes of carbon in the deep ocean and coastal sediment every year.[68] FAO claims that by 2050, farmed seaweed production could additionally absorb 135 million tonnes of CO_2 per year.[69]

Based on these false assumptions, CDR seaweed companies go on to offer some version of the following business plans:

a) "We will grow a large quantity of macroalgae biomass", either by expanding coastal seaweed farming, restoring natural kelp forests or increasing growth of deep ocean floating Sargassum.

b) "We will move carbon to the deep oceans". This thereby acknowledges that simply growing seaweed on the coast is not enough since most of the biomass washes ashore and decomposes.

c) "We will generate carbon credits". Some seaweed companies offer their own self-authored and self-certified seaweed-based carbon credits. Others are partnering with verification companies.

Seaweed financialization and carbon markets

While seaweed itself is a growing market (for food, for example) the big profit-focused promise of the seaweed revolution is to generate revenue from tradable carbon credits for sequestering CO_2. Carbon offsets are used by polluters to report "lower" greenhouse gas emissions by purchasing credits that supposedly offset their emissions with an activity somewhere else, which is alleged to be sequestering more atmospheric CO_2. Carbon credits and offsets are widely opposed by climate justice movements as they provide a means for big polluters to continue emitting greenhouse gases, a situation that will lead us to certain further global warming.[70] Furthermore, the Intergovernmental Panel on Climate Change's (IPCC) recent figures show that there is no place for offsets if we want to stop the increase of temperature.[71]

Notwithstanding, the UNFCCC is now establishing the ground and standards for a new global market in carbon credits, while voluntary markets have been in place for some time and are expected to grow to US$10-40 billion in value by 2030.[72] Demand for offsets and credits (by corporate players who have made carbon reduction promises) is expected to outstrip supply by 2024.[73]

In the frenzied search for new carbon credits, much attention is now turning to "blue carbon". The World Economic Forum has created a "Blue Carbon Buyers Alliance" to support a new "blue carbon" credit market.[74] Verra, one of the world's largest voluntary carbon trading program developers, has published the first "blue carbon" offset methodology and is now developing two credit methodologies covering seaweed farming, restoration and sinking.[75] Competitor Gold Standard is also looking into seaweed-based credits.[76]

It is important to note that there are significant questions concerning the reputation and integrity of voluntary carbon programmes and their carbon accounting technologies, as exemplified by the recent scandal over Verra's "phantom" forest carbon credits, after it was found that more than 96% of their rainforest offset credits do not represent real carbon reductions.[77]

Similarly, even enthusiastic supporters point to inherent difficulties in measuring for seaweed-based carbon credits. A recent report by McKinsey concludes: "There is no escaping the fact that blue carbon solutions are, for the most part, in their infancy. Just a trickle of projects have qualified for carbon markets to date, and there are significant financial, practical, and legal hurdles to scaling in ocean and coastal environments".[78] The McKinsey report also highlights "scientific uncertainty" as a "significant hurdle". For example, seaweed farming may not count as an "additional" CDR scheme as it is already expanding for food demand. Research also shows, as stated above, that farmed seaweed exhibits modest[79] or no sequestration in coastal seabed sediments, and there is scientific evidence that seaweed ecosystems can lead to a net release of CO_2.[80]

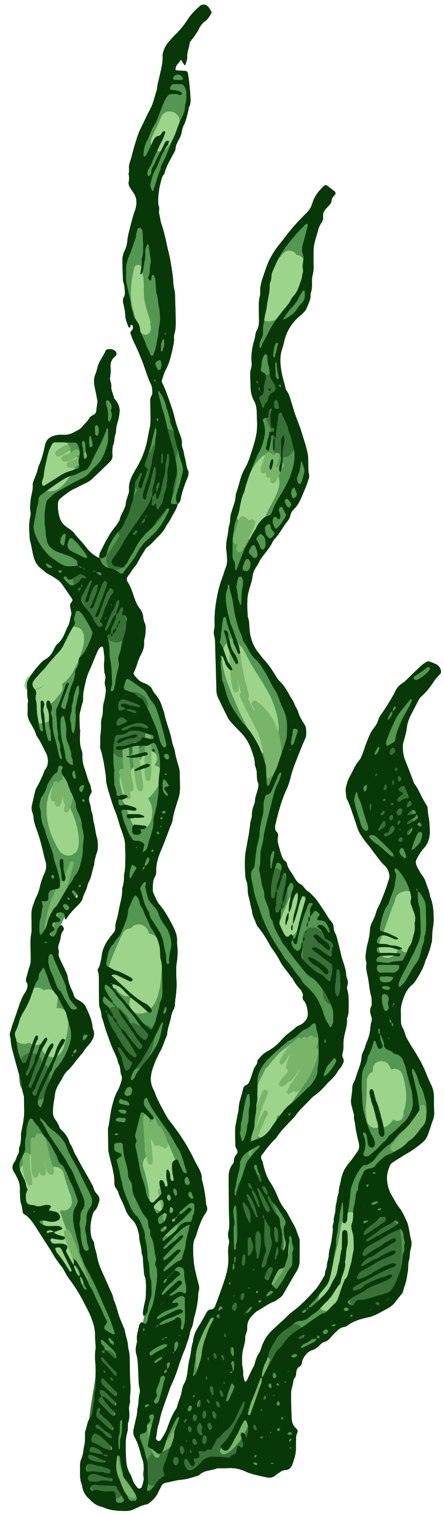
"We are talking about seaweed. It's a resource that grows ferociously, can scale as wide as the ocean and can capture vast amounts of carbon, making it a serious gigaton-level climate restoration solution." – Peter Fiekowsky, Geoengineering investor[65]

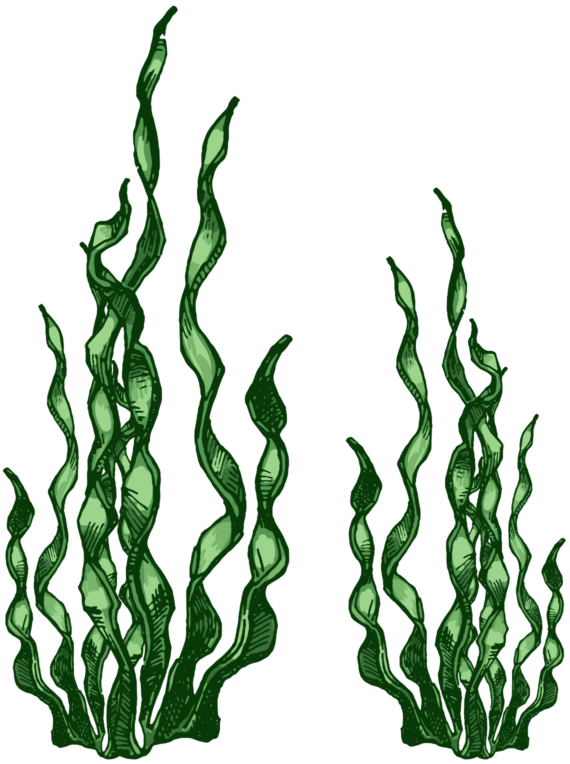
Even if a carbon-offset program for seaweed is fully implemented, the credits could prove cost-prohibitive. A 2022 estimate of the cost of using seaweed to sequester CO_2 using a baseline model found an exorbitant cost of US$17,048 per tonne of CO_2 – compared to US$2-11 for forest sequestration.[81] In the absence of formal markets, seaweed players such as Canopy Blue, The Seaweed Company and Running Tide have been selling carbon offsets to corporations without waiting for the science to settle.[82] Seaweed carbon credits are also being mixed with cryptocurrency and digital tokens – such as the digital "KelpCoin" issued by The Climate Foundation.[83]

Beyond carbon: betting on (and inventing) biodiversity markets

Seaweed start-ups are additionally claiming their plans will enhance biodiversity conservation and provide "ecosystems services" (a way of monetizing the ecosystem functions that nature provides). The financialization of these natural "services" was given a significant go-ahead in December 2022 with the agreement of the Kunming-Montreal Global Biodiversity Framework (GBF). Target 19 of the GBF committed countries to stimulate "innovative schemes such as payment for ecosystem services, green bonds, biodiversity offsets and credits, and benefit-sharing mechanisms".[84]

In view of this, there are increasing attempts to put a monetary value on seaweed ecosystem functions. For example, a 2022 study led by The Nature Conservancy (TNC)'s "Provide Food and Water Sustainably Team" estimated that the nitrogen removal "service" of seaweed farms could be worth US$84–505 per tonne of seaweed.[85] They also noted that seaweed-growing offers habitat to additional fish, which could reel in an additional US$972–2,504 per hectare per year.[86] The Nature Conservancy manages billions of dollars in land and ocean assets[87] and has a strong interest in scaling up and financializing seaweed farming in Belize, Indonesia and elsewhere – either to directly finance their activities or improve their credit-worthiness for controversial "debt-for-nature" swaps.[88]

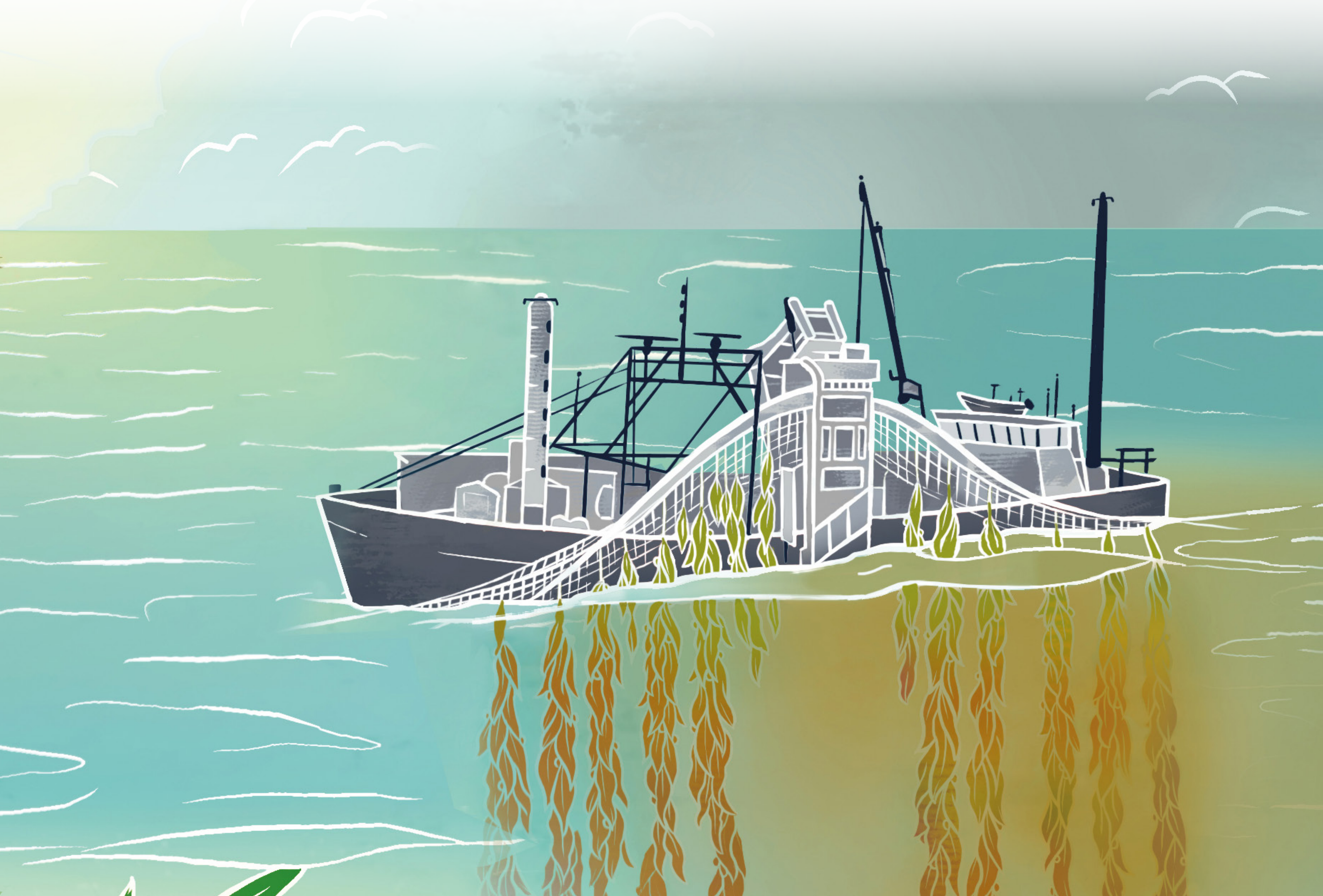




The new seaweed trade lobby and Big investors

Box 3: Seaweed through the corporate lens – market, players and prizes

Investment: More than a quarter of a billion dollars in commercial investment in the two years 2020 and 2021.[89]
Players: In mid-2023 there were more than 1,300 companies involved in commercial seaweed, including more than 200 start-ups.[90]
Market Prize: There is hope that industrial seaweed can grow profits via both food production and carbon credit sales. The seaweed food market is expected to be worth more than US$25 billion by 2028;[91] seaweed CDR schemes could contribute to a market worth a trillion dollars by 2050.[92]
Inexperienced players: Many new seaweed startups are led by individuals from software, finance, engineering or media with no prior experience in aquaculture, seaweed ecology, seaweed gathering or mariculture.[93]



Seaweed Trade Lobbies

These include The Global Seaweed Coalition (formerly The Safe Seaweed Coalition) whose members endorse the "Seaweed Revolution" manifesto.[94] Also notable is Seaweed for Europe launched in 2020 by SYSTEMIQ, a UK-based, self-styled "systems change" corporation that runs several other industry-focused coalitions.[95]

Geoengineers

Carbon Dioxide Removal is seen as a key geoengineering pathway. Geoengineering advocates boosting seaweed scale-up include:

- The Cambridge Center for Climate Repair (CCCR), UK, headed by Sir David King who served as the UK's Chief Science advisor to former UK Prime Minister Tony Blair and is affiliated with SYSTEMIQ.[96]
- Geoengineer Victor Smetacek (scientific advisor to and founder of Seafields).
- Geoengineering investor Peter Fiekowsky and his "Foundation for Climate Restoration".

Pilanthrocapitalists and related institutions

- In 2021 the Bezos Earth Fund (BEF) established by Amazon founder Jeff Bezos awarded US$100 million to global conservation group World Wildlife Fund (WWF), with a particular focus on seaweed scale-up and development.[97] In early 2023, Amazon's Right Now Climate Fund (the company pledged US$100 million in 2019 to support "Nature Based Solutions")[98] footed the US$1.5 million needed to establish a 10-hectare seaweed farm in the Netherlands as the first step toward a larger scale-out.[99]
- US-based ClimateWorks Foundation is a ubiquitous philanthropic presence funding seaweed industrialization. ClimateWorks prioritizes marine-based carbon dioxide removal in its grantmaking.[100] ClimateWorks Foundation also finances Ocean Visions, a collaboration by several United States universities and institutions that lobbies for the research and use of geoengineering techniques in the oceans, including seaweed cultivation and sinking for carbon removal.[101]

Other Big Tech, Big Conservation and Big Finance Players include Microsoft, Xprize Foundation (Elon Musk), Y Combinator ("startup accelerator"), Shopify, Stripe, De Beers, McKinsey & Co., World Bank, Asian Development Bank, The Nature Conservancy and Conservation International.[102]

Photo: Seaweed farm formations. Alex Berger, flickr.

Four proposed industrial seaweed schemes

1. Farm seaweed

"At the end of the day it's all about producing a large amount of quality biomass at a low price and the way you do it at a low price is through scale: by being large, by having, for example, a hundred hectare farm."
Mike Williamson, CEO of Cascadia Seaweed[103]

What? Many new business plans for seaweed industrialization focus on expanding the ocean acreage of seaweed farming. There are, theoretically, 48 million km^2 of coastal waters where macroalgae farming could be undertaken – an aggregate area about six times the size of Australia.[104] Companies such as Cascadia Seaweed or Kelp Blue promise to lead the way in transforming thousands of hectares of coastal ocean to growing seaweeds on lines, nets or platforms.[105] This activity is copying the already existing industrial seaweed farming scale-up that has occurred in parts of China, but would bring it to new geographies such as the coasts of Africa, the North Sea in Europe, around the Indian coastline, and along North American coastlines. Some seaweed farming operations are deliberately moving seaweed production into the deep oceans to enable a much wider scaling than is possible in just coastal waters.

In some schemes, new industrial seaweed farmers are taking out licenses from Indigenous communities for rights to farm offshore (e.g. Cascadia in British Columbia)[106] or proposing to mix seaweed farming with existing projects such as offshore wind turbine farms off the Netherlands coast.[107] Kelp Blue, which recently received a US$2 million investment from diamond mining giant DeBeers, is working towards establishing a 70,000 hectare seaweed farm at Luderitz in deeper water off the coast of Namibia. The company claims it will "have access" to 120,000 tonnes of kelp per year.[108] They hope to expand to manage "great barrier reef-sized" kelp farms in six locations worldwide.[109] Open-ocean seaweed farming is also being expanded to Sargassum – a floating nuisance seaweed. Seafields plans to seed and grow Sargassum in floating pens with the intention of increasing their Sargassum aquafarm until it reaches around 94,000 km^2 – an area slightly larger than Portugal.[110] Seafields is additionally proposing to place large ocean pipes in the water column to pump deep nutrient-rich water up to the ocean surface[111] – a geoengineering approach called "ocean mixing" or upwelling – with the intention of having enough nutrients in the open ocean pens to grow seaweed, and maybe an extra income from carbon credits.

> "We alert that the race to sink seaweed in the ocean is outpacing the rate of progress of the essential science to assess risks, surging past even perfunctory evaluation of the environmental impacts and social benefits." [114]

The promise: Firms such as Cascadia and Kelp Blue describe seaweed farms as "ocean afforestation".[112] Even though seaweed will be harvested and brought to land for processing, it is claimed that seaweed leads to some level of sequestration because of the "natural biological export" of seaweed biomass to areas beyond the seaweed farm itself. Companies that target deeper waters claim that biomass from their operations will more quickly be sequestered away in the deep oceans and may combine farming at sea with seaweed sinking (more on this below). Some farms claim seaweed growing provides additional habitat to wildlife, helps filter toxins and absorbs excess nutrients, cleaning oceans.

The problem: It is misleading to compare industrial seaweed farms with natural kelp forests, as the former are artificial monoculture habitats that have their own negative ecological and social-cultural impacts. Industrial seaweed farms occupy space and alter marine ecosystems by changing light levels and air and ocean chemistry. As researchers have cautioned,[113] it is unlikely that any significant amount of carbon will be sequestered overall in a coastal farming system, and moving seaweed-growing at an industrial scale into the open ocean has further unknown impacts. Seaweed farming companies such as Cascadia may still benefit from a climate-friendly image but probably do little to directly sequester carbon. Any use of "ocean mixing" technologies may bring previously stored CO_2 back to the atmosphere, negating the point of growing seaweed as a carbon dioxide removal technique.

2. Sink Seaweed

What? Probably the most visible and significant of the new "CDR" seaweed companies are those that claim they will grow or collect seaweed in order to sink it into the deep ocean. Carbon sequestration is their core business. "Sinking" refers to bringing a large amount of seaweed biomass, usually kelp or Sargassum, to an open ocean location and then physically/mechanically moving it below the waves into deep ocean to collect on the seabed. Proposed seaweed sinking techniques include using large nets, robotic submarines, and autonomous robots to transport seaweed to deep enough water to sink. Startups like Phykos[115] and Pull to Refresh[116] have developed open-ocean farming platforms and ocean-going autonomous vessels to grow and sink kelp. Running Tide is developing a method of growing kelp on temporary floating buoys that degrade, causing the kelp to sink.[117] Others, such as Seaweed Generation and Seafields, are focusing on sinking Sargassum.

The promise: Seaweed "sinking" proponents contend that at present very little natural seaweed biomass makes its way to the ocean sediment to be stored away as part of the long carbon cycle. By physically dragging material into the deep sea, "seaweed sinking" companies hope to increase the amount of carbon that can be reported as sequestered (and thereby earn more carbon credits). Indeed, Running Tide has already sold credits to high-profile buyers such as Microsoft, Chan Zuckerberg Initiative, Stripe and Shopify.[118] They claim that in deep ocean locations they can store away seaweed biomass for 1,000 years.[119]

The problem: Sinking seaweed biomass in the ocean is an entirely novel proposition that entails a scale-up of industrial activity in the difficult and complex environment of the open ocean. It won't be easy, cheap or impact-free. Growing seaweed species in a large area of open ocean will change local ecology and food chain dynamics. We also don't know how adding large amounts of seaweed biomass to the seabed will impact the marine communities there. A similar proposal from 2009 to dump agricultural biomass in the deep ocean was evaluated as raising concerns including "significant physical impact on the seabed due to the sheer mass of the material covering the seabed. In addition, there may be wider chemical and biological impacts through reductions in oxygen and potential increases in hydrogen sulphide, methane, nitrous oxide and nutrients (nitrogen and phosphorus compounds) arising from the degradation of the organic matter."[120]

Seaweed sinking proposals have prompted strong opposition among marine scientists. In August 2022 a group of academics, some associated with seaweed farming, issued an article titled bluntly, "Sinking seaweed in the deep ocean for carbon neutrality is ahead of science and beyond the ethics".[121] In their article, they warned of ecological risks of diverting nutrients and the impacts on deep sea biological communities: "We alert that the race to sink seaweed in the ocean is outpacing the rate of progress of the essential science to assess risks, surging past even perfunctory evaluation of the environmental impacts and social benefits. This lack of scientific evidence and of peer-reviewed procedures to verify success of the practice, however, has not prevented the private sector from currently offering carbon removal from sinking seaweed as an attractive marketable product where millions $USD have already been invested." They conclude, "the urgency to find solutions that help stem climate change does not justify the deliberate sinking of seaweed in the deep ocean without properly assessing the consequences."

3. Replace plastics, animal protein, fertilizers and feed with seaweed

What? Recent startups are promising to transform seaweed biomass as a feedstock for plastics, plant-based food and more. Seaweed is also used as a livestock feed and a biological fertilizer for agriculture, and firms are exploring turning seaweed biomass into charcoal and "soil amendments" that boost plant growth (referred to as "biostimulants"). At least 19 seaweed firms are creating plant-based snacks and protein products to be marketed as green, vegan and low carbon.[122] Red seaweeds in particular can have up to 47% of their dry composition as protein,[123] and the seaweed protein market is estimated to reach US$1.51 billion by 2030.[124] Meanwhile at least 36 companies are working on seaweed-based plastics.[125] Firms including Oceanium[126] and Cascadia Seaweed are setting up seaweed biorefineries with plans to process seaweed biomass into useful compounds for industrial biomaterials and ingredients. The growing interest in using seaweed as a biostimulant is also bringing big agrochemical and fertilizer corporations such as Yara (India and Norway), Syngenta, FMC, UPL and BASF into the seaweed industry.[127]

The promise: Seaweed companies claim that using seaweed as a "nature-based" feedstock will displace fossil-fuels and help "decarbonise" the economy. Others assert that seaweed can add 10% to the world's present supply of food, freeing up land to be re-wilded rather than farmed.[128] Some believe that selling alternative protein from seaweed will decrease consumption of meat and dairy, in turn reducing overall carbon emissions (from animal agriculture). Advocates of seaweed-based fertilizer point to replacing greenhouse emissions from fertilizer production.

Feeding seaweeds to cattle is also claimed to significantly lower emissions of methane, a potent greenhouse gas. *Asparagopsis taxiformis* (a red seaweed) produces a compound called bromoform, which inhibits methane-making bacteria in cattle stomachs. Studies show adding small quantities of this seaweed to the diet of ruminant animals reduced methane emissions from 40-98%.[129] Big claims are also made for using seaweeds as plant "biostimulants" to push up yields.[130]

The problem: Expanding seaweed's use as a protein source does not guarantee the displacement of other, more climate-unfriendly protein sources. Even while alternative protein sales surged 54% between 2018 to 2021,[131] sales of meat and dairy also grew in that same period, and there is little evidence of replacement occurring. Instead "big protein" corporations are creating an additional revenue stream for themselves.[132] Thus the argument that the "replacement" of protein sources will lead to lower carbon emissions is unproven.

Breaking down algal biomass at scale, e.g. via biorefineries, is also likely to depend on risky biotechnologies, and require the construction of an extensive logistics chain to gather, dry, process and transport seaweed while dealing with factors such as mold and infestations. Wet seaweed is energy-heavy to carry and to dry, which has led to proposals for biorefineries to be sited at sea to reduce distance – but this approach seems very likely to bring new potential risks to the marine environment. Overall, turning seaweed into biofuel is particularly unrealistic. Trade group Seaweed for Europe notes: "The cost profile for conversion of seaweed to fuel will not fall sufficiently over the next 10 years to allow seaweed-derived biofuels to compete with alternatives". [133]

Using seaweed as livestock feed raises serious questions too. Researchers point out that the main seaweed-sourced substance that inhibits methane production – bromoform – is toxic to both animals and humans and may turn up in milk and urine. "It is not without reason that there are limits for the maximum amount of bromoform in drinking water", explains Wouter Muizelaar, researcher at Wageningen Livestock Research; "The fact that the substance can now also be found in the milk is extra worrying".[134] Since bromoform is also ozone-depleting, scaling up high-bromoform seaweeds for cattle feed may increase ozone depletion.[135]

4. "Rewild and restore" seaweed

What? While most seaweed industrialists focus on expanding acres of farmed seaweed, natural kelp forests are rapidly disappearing in some regions due to climate impacts and human development. Researchers have recently estimated the value of the "ecosystem services" provided by kelp forests at US$500 billion per year[136] and some firms are betting that they can earn dollars for pursuing kelp protection, ecosystem restoration, and re-wilding activities in a future biodiversity finance market. Although there is currently no formal marketplace in biodiversity, the potential for biodiversity credits (including "charismatic"[137] carbon credits) is becoming more apparent following the 2022 Montreal Biodiversity Summit. For instance, take the award of the world's first ever "blue carbon credits" for kelp restoration to urchin-gathering startup Urchinomics by the Japan Blue Economy Association,[138] and also the activities of UK rewilding company Mossy Earth, which sells credits for seaweed restoration off the coast of Portugal.[139]

In addition to so-called "re-wilding", startups are seeking to profit from "cleaning up" invasive and nuisance seaweeds, such as the Sargassum that is currently impacting many coastal activities in the Caribbean and Central America. Some firms propose to harvest the Sargassum and either sink it at sea or process it into high-value materials.[140] Multi-trophic aquaculture[141] is another proposal that involves growing seaweed in the midst of other aquaculture activities to create mixed production systems where waste and nutrients from one aspect of the production system feed other parts.

The promise: Unlike farming or sinking, seaweed "re-wilding" doesn't create an artificial biomass supply chain. It directly addresses an acute ecological problem: the serious loss of natural kelp forests. For example, California experienced a disastrous 95% loss of natural bull kelp forest canopy between 2008 and 2019 with large amounts of purple sea urchins replacing

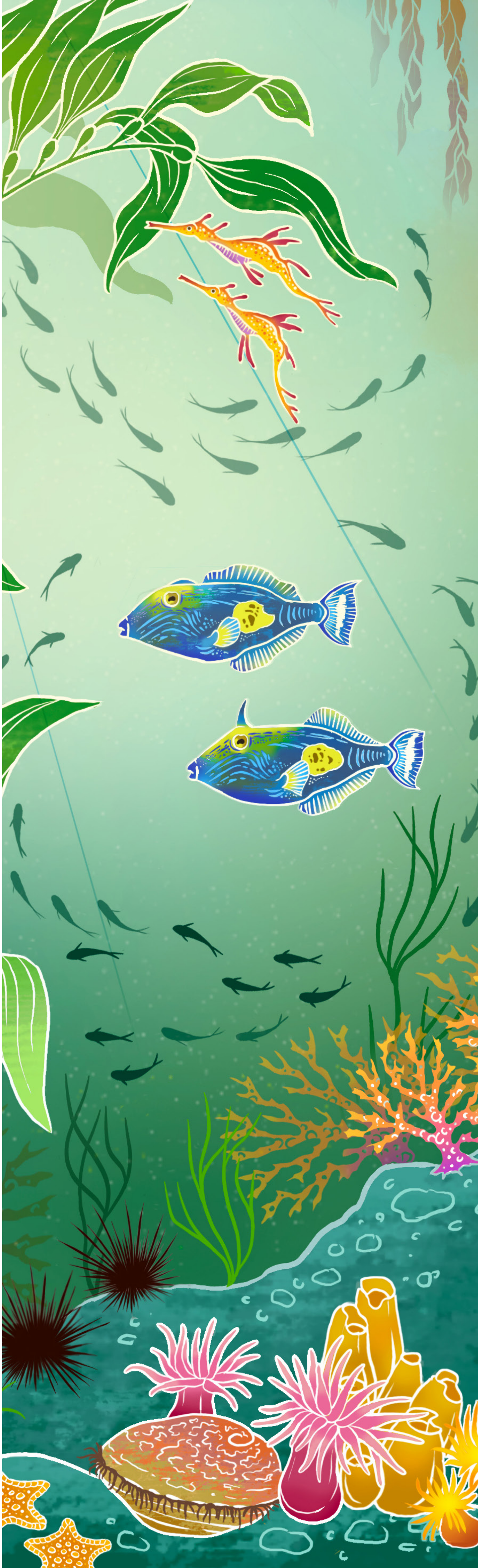
Photo: Benjamin L. Jones, Unsplash.

the seaweed (creating what are known as "urchin barrens").[142] In such a situation, "reforesting" the natural kelp improves regional ocean ecosystems and might be scaled up quickly. Likewise, the impact of Sargassum on Caribbean tourism, fishing and coastal ecology is a major challenge for the affected country governments. Thus gathering, sinking and processing Sargassum appears to be an attractive technofix. Multi-trophic aquaculture raises the opportunity to increase fish protein catch and other co-products as well, in an attempt to create more ecological, circular production systems.

The problem: So far so good. But wild seaweed has already been "saving the planet", long before industrialists and financiers attempted to place themselves into the equation. These ecosystems have by and large been cared for by coastal communities, Indigenous and peasant fisheries and algae cultivators. The erosion and devastation of these systems has happened in spite of their efforts and has been caused by a range of industrial activities and pollution. Handing the conservation and restoration of seaweed ecosystems over to private firms required to turn a profit raises significant concerns about the displacement of livelihoods, the financialization and privatization of nature, conservation and marine resource grabbing. Financialized land-based conservation programmes (e.g. REDD+) have seen traditional lands seized, community control disrupted and the rise of militarized "fortress conservation" as organizations navigate the dual (and often competing) purposes of conservation and realizing a financial return. The human rights of Indigenous Peoples, fishers and peasants are often the first casualty of privatized conservation. Furthermore, bringing private financing and the drive to make a profit into a supposed pollution clean-up (such as Sargassum harvesting) may create perverse incentives to avoid addressing root causes (i.e. the problem that creates excess Sargassum must persist in order for profits to persist).

Many Indigenous and traditional communities strongly resist reducing both ecosystem functioning and cultural relationships with the ocean to the financial language of "ecosystem services" and biodiversity pricing. Hundreds of years of history show that once a price is established on their territories and natural relations, colonial expropriation is facilitated. In cases where handing over territorial rights to conservation and seaweed farming enterprises happens, some Indigenous groups may be unaware that this may be facilitating a new green colonial grab. In reality, the "rewilding" and "afforestation" language is often little more than a PR label for industrial farming activities that are nothing to do with restoring natural kelp forests.[143]

> "Kelp farming is a monoculture—the marine equivalent of terrestrial industrial tree plantations. Monocultures differ from naturally functioning ecosystems in that they extirpate naturally occurring species and disrupt natural dynamics, lack biological diversity, act as foreign pathogen vectors, lack resilience to threats, and require cyclical harvesting."[144]



Seaweed, and the Human Rights of Indigenous Peoples, peasants and fisherfolk

The rapid industrialization of seaweed poses a threat to traditional coastal cultures and economies, particularly Indigenous communities, with their practices and knowledge, who have a vital role in caring for these ecosystems and increasing their biodiversity. Monoculture seaweed production could contaminate or displace fishing and gathering grounds, which are crucial to coastal ways of life.

The existing Human Rights of and decision-making by traditional coastal communities, artisanal algae cultivators, seaweed gatherers and Indigenous Peoples are threatened by the pursuit of carbon and biodiversity finance payouts from industrial seaweed farming and other activities for profit. Traditionally cultivated and natural seaweeds are culturally significant, vital for food security, and an important part of coastal communities' traditional livelihood and cultures, and are thus entwined with Human Rights concerns.

Some seaweeds may constitute "cultural keystone species". The concept of "cultural keystone species" was established specifically through the study of British Columbia's Indigenous groups and their relationship with Red Laver Seaweed (as well as with Western Red Cedar and the staple traditional root vegetable known as wapato).[145] The International Panel on Biodiversity and Ecosystem Services (IPBES) has recognized that wild species such as seaweeds are essential to the well-being of Indigenous Peoples and Local Communities.[146]

In some areas, Indigenous rights and lifeways have already become a significant issue in the debate over seaweed industrialization. While some Indigenous communities have accepted to negotiate with seaweed producers to lease traditional grounds,[147] others have expressed strong opposition. An example is the Intertribal Sinkyone Wilderness Council representing ten Northern California Indigenous Tribes, whose traditional territories extend far into the Pacific Ocean. In a 2021 letter to the California legislature, the Council explained: "The Tribes have witnessed a series of continuous assaults on the marine environment that have caused the extinction and serious decline of numerous species and habitats".[148] The Sinkyone reject so-called "green" claims of seaweed farming and asked the legislature not to confuse natural kelp beds with monoculture farms. The Council wrote: "We are unequivocally opposed to any commercial kelp mariculture enterprises or activities. Kelp farming is a monoculture—the marine equivalent of terrestrial industrial tree plantations. Monocultures differ from naturally functioning ecosystems in that they extirpate naturally occurring species and disrupt natural dynamics, lack biological diversity, act as foreign pathogen vectors, lack resilience to threats, and require cyclical harvesting." [149]

Precautionary Governance

Governance in relation to seaweed

Policy-making about seaweeds ranges across several domains of national, regional and international governance, but decision-making over the sea is contested and complicated.

Indigenous Peoples, fisherfolk and peasants

Governance related to seaweeds should not be reduced to regarding them as "biomass" or "marine resources"; they should never be isolated from their important historical and present social and economic relation to the communities that have traditionally cultivated them.

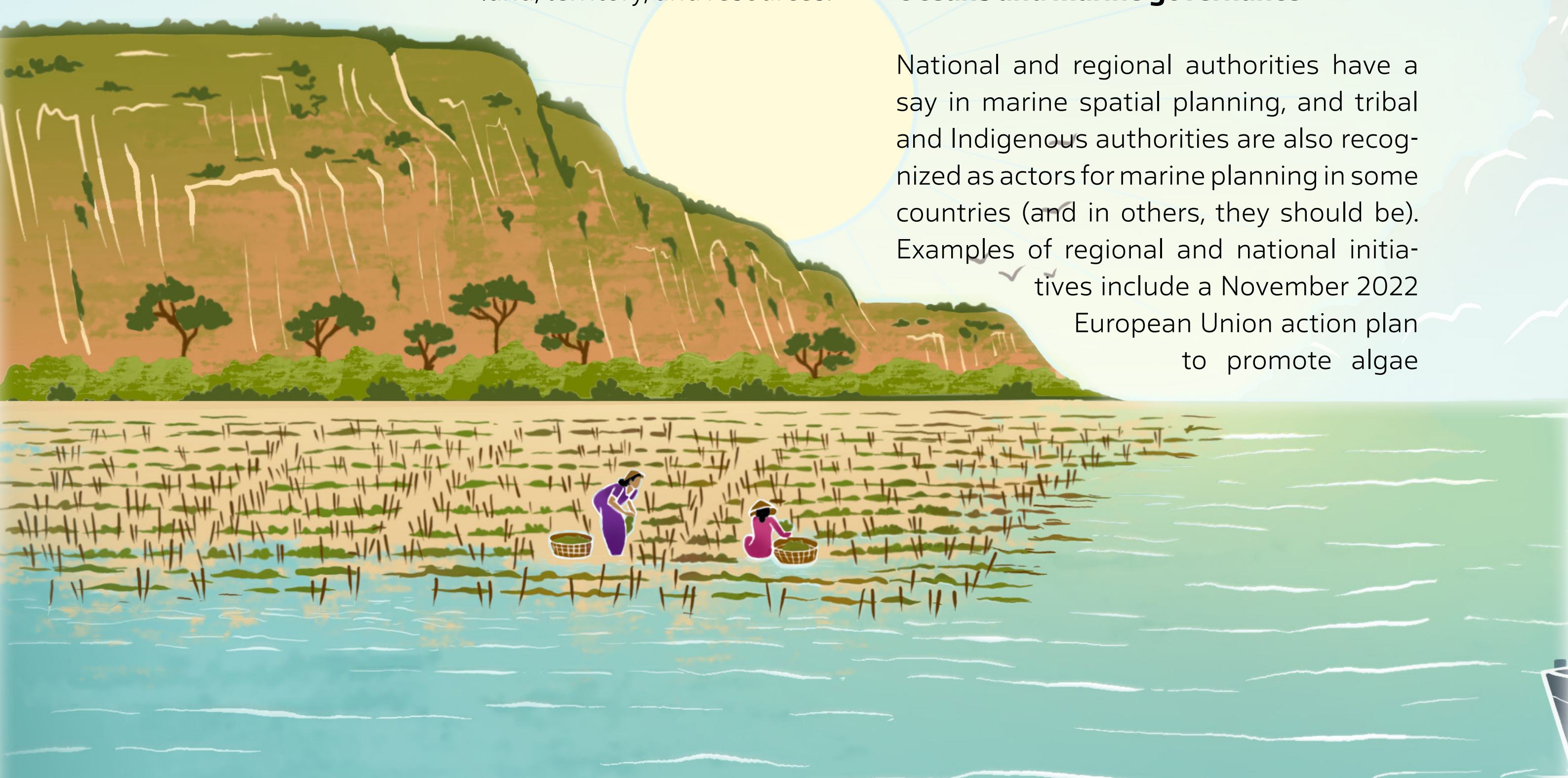
The UN Declaration on the Rights of Indigenous Peoples (UNDRIP) underscores the importance of obtaining Free Prior and Informed Consent for any activities that affect the rights of Indigenous Peoples to land, territory, and resources.[150]

Indigenous Peoples must be correctly informed (including prior to development of projects) about the environmental impacts and risks of seaweed farming, including not being made overblown promises involving carbon credits and climate benefits. The UN Declaration on the Rights of Peasants and other People Working in Rural Areas (UNDROP)[151] also highlights the rights to prior informed consent of coastal communities engaged in fishing and gathering, including seaweed. It specifies that people have the right to access and use natural resources sustainably.

The placement of seaweed production facilities in traditional fishing and gathering areas, particularly if they negatively impact wild populations, could undermine the rights established in these Declarations.

Oceans and marine governance

National and regional authorities have a say in marine spatial planning, and tribal and Indigenous authorities are also recognized as actors for marine planning in some countries (and in others, they should be). Examples of regional and national initiatives include a November 2022 European Union action plan to promote algae



growing.[152] The US Congress introduced a bill in 2023 to promote seaweed industrial farming although the bill also established a fund which refers to Indigenous nations.[153]

Internationally, seaweed farming at sea and seaweed sinking proposals could come under the oversight of the newly agreed High Seas Treaty, but that will only come into force when ratified by 60 countries.[154] The London Convention and London Protocol (on dumping of matter at sea) have taken responsibility to determine regulation of marine geoengineering activities[155] – this should include seaweed-sinking and high seas seaweed-growing. Decisions over the marine environment must also be consistent with the UN Convention on the Law of the Sea (UNCLOS). The UN also maintains a "Regular Process for Global Reporting and Assessment of the State of the Marine Environment including Socioeconomic Aspects", creating a ***World Ocean Assessment***.[156] This assessment is now in its third cycle and may consider issues related to industrial seaweed-cultivation.

Climate governance

Under the UNFCCC, seaweed's role in climate and ocean life has emerged in the Ocean Dialogues. Most worryingly, discussion about its scale-up appeared in talks about carbon market mechanisms – as a means of generating profit. A Supervisory Body for Article 6.4 of the Paris Agreement[157] has been established to study and make proposals on sources for carbon removals, including marine and other geoengineering technologies. The seaweed industry and allies are pushing for seaweed-farming and seaweed-sinking to be recognized as carbon dioxide removal approaches in new carbon markets. But precautionary decisions relating to marine geoengineering in the Convention on Biological Diversity (CBD) and the London Convention/London Protocol (as mentioned above and below) must be respected. The fact that seaweed ecosystems may not be the significant carbon sinks they have been promoted as, but may even be carbon sources, must lead to the exclusion of seaweed-farming and seaweed-sinking from all discussions about carbon markets and carbon removal strategies in the UNFCCC's Article 6 discussions and elsewhere, including voluntary markets.

Food governance

Since seaweed is an ocean food and used in agriculture as feed, fertilizer and biostimulants, the UN Food and Agriculture Organization (FAO) monitors seaweed developments and released an overview of global production in 2021.[158] A joint report with the World Health Organization on seaweed-based food safety was also released in 2022, recommending the development of health and safety standards by the Codex Alimentarius.[159] The FAO is preparing a roadmap "to make food systems more sustainable",[160] which may address seaweed's climate-related claims. Neither the FAO nor the Committee on World Food Security has addressed the impact of seaweed industrialization on traditional and Indigenous food ways, including the displacement of fishing and coastal food activities.

Biodiversity governance

As seaweed proponents widen their focus to biodiversity-benefits and biodiversity-financing, the Convention on Biological Diversity (CBD) may prove to be an important forum for oversight and the precautionary regulation of seaweed industrialization. The CBD protects marine and coastal biodiversity and sustainable use of biodiversity by Indigenous Peoples and Local Communities. Both the CBD and the International Panel of Experts on Biodiversity and Ecosystem Services (IPBES) stress the importance of protecting wild species, particularly for cultural and ecological reasons and recognize the essential role played by Indigenous Peoples and local communities. Targets 4, 5, 6 and 9 of the Kunming-Montreal Global Biodiversity Framework approved in 2022 emphasize genetic diversity, sustainable use of wild species, risks of invasive species, and the importance of protecting Indigenous Peoples and Local Communities' customary use.[161]

Conclusions and Next Steps

We need a sea-change in policy to defend the Seaweed Commons!

While seaweeds are not a magical climate fix, they are still deeply important. They deserve a movement to defend them, their habitats, and the communities and Indigenous peoples that have nurtured them over centuries, rather than a rush to turn them into an industrial monoculture.

Unfortunately, we have seen this kind of rush before. For example, around 2005-2010, big "green" groups, tech investors, and some climate activists enthusiastically endorsed and pushed for the scale-up of biofuels and biomass-based electricity. It took a global food crisis, violent land grabs, and an outcry by farmers and food sovereignty movements to get them to reluctantly cool their enthusiasm. They finally acknowledged that the science of land use change meant that their initial carbon sequestration assumptions for bioenergy were wrong[162] (even so it has taken some years for policy-making to catch up with the science). Lessons need to be learnt much more quickly with seaweed.

Just as with biofuels, the science about carbon sequestration via seaweed is now

becoming clearer, particularly with studies showing the potential net release of carbon from seaweed ecosystems, especially farmed seaweed ecosystems. Big "green" groups and climate philanthropy must recognize the limits of industrial seaweed farming and its potentially serious impacts on traditional communities, Indigenous Peoples and the environment, and put a hard brake on the industrial seaweed-as-saviour rhetoric.

We need to focus on what really matters – protecting natural seaweed populations, and the cultures and traditional small-scale seaweed economies that steward them, including against attempts to industrialize and financialize them.

The rights of Indigenous Peoples, fisherfolks, peasant, coastal communities, and traditional algae cultivators, including their rights to consultation and Free Prior and Informed Consent for any activities that affect the rights of Indigenous Peoples to land, territory, and resources must be honored and implemented, as emphasized, for example, by the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) and the UN Declaration on the Rights of Peasants and other People Working in Rural Areas (UNDROP). Industrial deployment of seaweed production in traditional fishing and gathering areas undermines these rights.

To create a much needed sea-change in seaweed policy, governments should therefore:

- **Prohibit** industrial seaweed farming and sinking, including its licensing and expansion. As a first immediate step, a moratorium on its deployment should be established.

- **Exclude** seaweed farming and sinking from all Article 6 discussions in the UNFCCC and prevent its inclusion in any carbon removal or carbon market scheme, including voluntary markets.
- **Establish** precautionary rules, developed together and agreed with Indigenous Peoples and traditional coastal communities, to protect wild seaweeds, their ecosystems and traditional livelihoods.

- **Ensure** that seaweed activities are kept small-scale, culturally appropriate and based on ecological cultivation.

- **Ban** the release of genetically modified seaweed or other GM organisms in seaweed and related ecosystems.

- **Implement** strong rules to govern seaweed restoration to ensure that it is community-led, emphasizing traditional sustainable and customary use and protection of seaweed, not financialization, and ensure that any project involving it is based on a process of consultation and Free Prior and Informed Consent with affected Indigenous Peoples and coastal communities.

- **Advance and provide** funding for precautionary and participatory technology assessment and multidisciplinary research into the reality of claims relating to seaweed as a carbon sink, a replacement for proteins, a biostimulant and a source of animal feeds, and proposed technological interventions such as genetic engineering and automation, enabling a full investigation into related concerns about cultural, economic and environmental impacts, including related safety and biosafety questions.

The livelihoods, cultural and traditional practices of seaweed gatherers, Indigenous Peoples, and coastal communities where seaweed is a keystone cultural species must be prioritized, recognized and protected. It is time to act to protect seaweed as a traditional livelihood and a commons for future generations.

Annex 1

A Partial Selection of Seaweed Companies

Name of Company	Website	Country	Type of Seaweed	Business model	Climate /Carbon Claims?	Carbon credits or certificates
Arctic Seaweed	https://aseaweed.com	Norway	Kelp	SEAWEED FARMING/ AUTOMATION.	Yes	Yes
Akua	https://akua.co/	NY, USA	Kelp	SEAWEED ALTERNATIVE PROTEIN.	Yes	
Algae Demo Project	https://www.algaedemo.eu/the-project/	EU (Netherlands/ Belgium)	Sugar Kelp, Wakame	SEAWEED FARMING/ AUTOMATION		
Atlantic Sea farms	https://atlanticseafarms.com	USA	Kelp	SEAWEED FARMING:		
Australis Holdings (Greener Grazing)	https://www.greenergrazing.org/project	USA / Vietnam	Asparagopsis Taxiformis	SEAWEED FARMING FOR CATTLE FEED:	Yes	
Biome Algae	https://www.biomealgae.co.uk/seaweed	UK	Sugar Kelp, Wakame	SEAWEED FARMING/ BIOREFINERY:		
Blu3	https://blu3.io	San Francisco, USA		SEAWEED SUPPLY CHAINS	Yes	Yes
Blue Evolution	https://www.blueevolution.com	California and Alaska , USA	Kelp	SEAWEED BREEDING/ FARMING	Yes	
Bzeos	https://www.bzeos.com	Oslo, Norway		SEAWEED PLASTICS		
Canopy Blue /Grey Innovation	https://canopyblue.co	Western Australia	Kelp	SEAWEED FARMING	Yes	Yes
Cascadia	https://www.cascadiaseaweed.com	British Columbia, Canada	Kelp	SEAWEEED FARMING/ FOODS/ BIOREFINERY	Yes	Yes
Climate Foundation	https://climatefoundation.org	Seattle, USA		SEAWEED FARMING OEN OCEAN/ SINKING	Yes	Yes
Dutch Seaweed Group	https://www.dutchseaweedgroup.com/en/	Netherlands	Sugar Kelp and Wakame	SEAWEED FARMING.		
Everything Seaweed	https://www.everythingseaweed.net	Maine, USA		SEAWEED BIOREFINERY		
Fearless Fund	https://www.fearlessfund.org	USA	Sargassum	SARGASSUM REMOVAL/ GROWING:	Yes	
First Gigaton / Sea Cat	https://www.sea.cat	Phillippines		SEAWEED FARMING	Yes	
Greenwave	https://www.greenwave.org		Kelp	SEAWEED FARMING	Yes	

A Partial Selection of Seaweed Companies

Name of Company	Website	Country	Type of Seaweed	Business model	Climate /Carbon Claims?	Carbon credits or certificates
						(continuation)
Hortimare	www.Hortimare.com	Netherlands	Various	SEAWEED BREEDER		
Kelp Blue	https://kelp.blue/	Namibia, Alaska, new Zealand	Kelp	SEAWEED FARMING/ BIOREFINERY:	Yes	
Kelpi	Kelpi.net	UK	Kelp	SEAWEED PLASTIC		
Loliware	https://www.loliware.com	NY, USA		SEAWEED PLASTIC	Yes	
Nordic Sea farms	https://en.nordicseafarm.com	Gothenburg, Sweden	Kelp	SEAWEED FARMING	Yes	
Notpla	www.notpla.com/	UK		SEAWEED PLASTIC		
Oceanium	https://oceanium.world	Scotland	Kelp	SEAWEED BIOREFINERY		
Ocean Rainforest	https://www.oceanrainforest.com	Faroe islands / california	Kelp	SEAWEED FARMING/ SEAWEED BASED MATERIALS	Yes	
Ocean Regenerative	https://www.oceanregenerative.com	British Columbia, Canada	Kelp	SEAWEED FARMING/ BIOREFINERY	Yes	
Origin by Ocean	https://www.originbyocean.com	Helsinki finland		SEAWEED BIOREFINERY:		
Phykos	https://www.phykos.co	USA	Kelp	SEAWEED AUTOMATION/ SINKING		
Primary Ocean	http://www.primaryocean.com	Los Angeles, USA		SEAWEED FARMING/ BIOREFINER	Yes	
Pull to Refresh	https://pulltorefresh.earth	Colorado USA	Sargassum	SARGASSUM COLLECTION/ AUTOMATION/ SINKING	Yes	Yes
Running Tide	www.runningtide.com	Maine, USA	Kelp	SEAWEED FARMING/ AUTOMATION/ SINKING	Yes	Yes
Sea 6	www.Sea6energy.com	Bangalore India, Also Indonesia		SEAWEED FARMING/ AUTOMATION		
Seafields	https://www.seafields.eco	UK	Sargassum	SARGASSUM FARMING/ SINKING	Yes	Yes
Seaweed Carbon Solutions	see https://www.dnv.com/news/commencing-carbon-capture-with-seaweed-228139	Norway	Kelp	SEAWEED FARMING/ SINKING/ BIOCHAR:		
Seaweed Generation	https://www.seaweedgeneration.com	Uk	Sargassum	SARGASSUM SINKING/ AUTOMATION OF FARMING	Yes	Yes

A Partial Selection of Seaweed Companies

(continuation)

Name of Company	Website	Country	Type of Seaweed	Business model	Climate /Carbon Claims?	Carbon credits or certificates
Seaweed Solutions	https://seaweedsolutions.com	Norway, Portugal		SEAWEED FARMING IN OPEN OCEAN		
SOS Carbon	https://soscarbon.com/about-us	USA	sargassum	AUTOMATION oF SARGASSUM COLLECTION:		Yes
The Southern Ocean Carbon Company	https://southernoceancarbon.com	Tasmania Australia	Kelp	SEAWEED FARMING/ BIOCHAR.	Yes	
Sway the future	https://swaythefuture.com	Oakland, USA		SEAWEED BIOREFINERY:		
Tango Seaweed	https://www.tangoseaweed.no	Norway	Kelp	SEAWEED FARMING	Yes	Yes
Tend Ocean	https://www.tendocean.com	USA		SEAWEED AUTOMATION	Yes	
The Seaweed Company	https://www.theseaweedcompany.com	Netherlands, ireland, india, Morocco	Various	SEAWEED FARMING and FOOD.	Yes	Yes
Urchinomics	https://www.urchinomics.com/faqs/	Norway, Japan	Kelp	KELP RESTORATION/ URCHIN FARMING	Yes	Yes
Volta Greentech	https://www.voltagreentech.com	Sweden	Asparagopsis Taxiformis	SEAWEED CATTLE FEED:	Yes	

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