SEAWEED AS A NATURE-BASED CLIMATE SOLUTION
VISION STATEMENT

UN GLOBAL COMPACT

OCEAN STEWARDSHIP COALITION

CONTENTS

FOREWORD

Although it might be new to many, seaweed is an unlikely climate champion. It has significant potential to help build the safe, sustainable and prosperous future we want. Seaweeds can provide the inputs for a range of low-carbon products that can help decarbonize the economy while supporting efforts to rapidly reduce atmospheric levels of CO_2. Moreover, this nature-based climate solution has enormous potential to contribute to a restored ocean that is teeming with life. As one of the lowest trophic levels, it can help regenerate ocean biodiversity and support nutrient cycles.

We are on the cusp of a seaweed revolution that is scaling up production and ushering in new innovations to support the transition to a more sustainable future. Seaweeds can be used to support food security all over the world. They can be used as food, animal feed or plant bio-stimulant. They can add solutions for biodegradable plastics to eradicate plastic pollution and represent vast potential for innovation in medicine. The growing seaweed industry can also create cascading societal benefits through distributed and inclusive value chains that provide decent jobs within coastal communities

While the many benefits of seaweed are becoming well-known, they are rarely expressed together to provide a complete picture of its potential — as we have done in this statement. Recognition of seaweed's role as a climate solution, including through inclusion in countries' Nationally Determined Contributions, will be key to scale up new seaweed businesses and restoration initiatives to help support seaweed pioneers and entrepreneurs.

As stated in the Seaweed Manifesto (2020) last year: "A restored ocean and seaweed farming forests should be considered carbon sinks to mitigate climate change. (...) Recognizing the role of seaweed as a carbon sink at the UNFCCC (United Nations Framework Convention on Climate Change) level and making it part of its future COP discussions will be key."

Our vision is for a responsible, safe, sustainable and scientifically grounded seaweed industry to emerge at scale in the coming decades. In some cases, invasive species of seaweed can be a liability and undermine local biodiversity, if not managed correctly. Safety is therefore paramount and we need to ensure we do not reproduce errors made on land, such as monocultures, abusive use of pesticides, destruction of genetic diversity, land pollution, labour exploitation and child labour, while ensuring that we move with the pace required by the urgency of the climate crisis.

> **"We can achieve such objectives, but we need to first convey the potential as it can only be done together!"**
>
> **Vincent Doumeizel**
> Special Advisor, United Nations Global Compact

INTRODUCTION

THE PURPOSE AND NEED FOR A VISION STATEMENT

THE PURPOSE OF THE STATEMENT IS TO:

Position seaweed, or marine macroalgae, as a significant nature-based climate solution with large scaling potential that can directly sequester carbon and indirectly displace greenhouse gas emissions in numerous ways, with clear economic and ecological co-benefits that make it a form of "charismatic carbon" and a holistic nature-based climate solution.

A VISION STATEMENT IS NEEDED TO:

Highlight and inform

- On the variety of approaches for using seaweed as a nature-based climate solution.
- The fact that in several regions natural seaweed forests are in decline,[1] with 80–95 per cent losses of many canopy forming kelp forests in some areas of the Pacific Ocean and that active measures are needed to ensure both their protection as well as their regeneration so that they can continue providing ecosystem services, including carbon sequestration.
- The fact that harvesting of wild seaweed need to proceed responsibly and sustainably and should not be a driver of loss.
- The fact that cultivated seaweed and wild seaweed forests could make a large contribution to blue carbon sequestration but are not currently included in blue carbon budgets, due to scientific uncertainty and issues pertaining to carbon verification, quantification and accreditation.

Engage and communicate

- With Governments, investors, businesses, wider society, non-profits, academia and coastal communities to promote seaweed as a nature-based climate solution with cascading ecological and social benefits.
- That coastal and island states should explore and consider integrating seaweed cultivation and potentially seaweed forests into their Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) under the Paris Agreement.

Foster support

- To scale up production independent of carbon pricing, based on the widely recognized ecosystem services and productive uses of seaweed.

SCOPE

This document will focus specifically on seaweed within the broader blue carbon context. The document puts forward four mitigation opportunities in which seaweed can and could sequester carbon and three ways to activate this nature-based climate solution.

The authors fully acknowledge that microalgae, mangroves, seagrass and other blue carbon ecosystems play a critical role in sequestering carbon. Moreover, efforts to increase seaweed cover and the scale of seaweed farming will most likely affect other blue carbon pathways and many other elements of the complex interconnected system of which seaweeds are a part of. However, this vision statement deliberately focuses on seaweed, a largely untapped resource with significant capacity to scale, while providing solutions for limiting carbon emissions and sequestering meaningful amounts of carbon.

One of the main advantages of seaweed is that, over time, it is a form of "charismatic carbon" (Froehlich et al., 2019) meaning it also has multiple economic, ecological and social benefits beyond carbon sequestration. While seaweed is not a silver bullet to climate change, it could play an important role in decarbonizing the economy and contribute in multiple ways to the portfolio of carbon sequestration solutions needed in the decades ahead to keep global temperatures below 1.5 degrees.

1. Wernberg et al., (2016: p 90–93) https://portals.iucn.org/library/sites/library/files/documents/2016-046_0.pdf

CONTRIBUTORS

This vision statement has been developed under the auspices of the United Nations Global Compact Sustainable Ocean Business Action Platform. The editorial team is made up of selected representatives from academia, business, non-governmental organizations and UN specialized agencies. The document is a consolidation of input from participants, group discussions and relevant scientific reports and material.

It should be noted that the content does not necessarily reflect the position of all participating or cited organizations. The key contributors to the vision statement are listed below:

Editorial Board

- Vincent Doumeizel, UN Global Compact and Lloyd's Register Foundation
- Martha Selwyn and Mary Kate Currey, UN Global Compact

Editorial Team

- Adrien Vincent, Systemiq
- Brad Ack, Oceans Vision
- Daniel Hooft and Caroline Slootweg, Kelp Blue
- Edwin Aalders and Sarah Danielson, DNV
- Fred Puckle Hobbs and Paddy Tarbuck, Sea Green
- Jorunn Skjermo, Sintef
- Megan Reilly Cayten, Oceans 2050
- Paul Dobbins, WWF US
- Sam Zak and Brian von Herzen, the Climate Foundation
- Shaun Fitzgerald, Centre for Climate Repair, University of Cambridge

Acknowledgements

We are extremely grateful for the contributions submitted by Blue Road participants. The contributions of the following experts to the meeting and subsequent discussion are gratefully acknowledged.

- Antje Boetius, Bela Buck, Matthew Slater; Alfred-Wegener Institut
- Alyson Myers, Fearless Fund
- Amy Schmid, Verra
- Carlos M Duarte, King Abdullah University of Science and Technology (KAUST)
- Carlos Drews, Ocean Wise
- David Antoniol, Verra
- David King, Centre for Climate Repair, University of Cambridge
- Finnley Ross, Blue Carbon Lab, Deakin University
- Fiona Trappe The Seaweed Alliance & Seas The Opportunity
- Flower Msuya, University of Dar es Salaam
- Gwang Hoon, National Research Laboratory (NRL) of Korea
- Hiroko Muraki Gottlieb, Harvard Business School
- Haibo Chen, Lloyd's Register Foundation
- Jaime Webbe, Alinea
- Jan Verbeek, SeaForester
- Mar Fernández-Méndez, AWI & GEOMAR
- Maximiliano Bello, Mission Blue
- Philippe Potin, French National Centre for Scientific Research, CNRS
- Randall Purcell, Seafields
- Ross Brooks, Katapult Ocean
- Rod Fujita, Environmental Defence Fund (EDF)
- Simon Davis, SEEDLING
- Úna Brosnan, Mainstream Renewable Power

ROAD MAP

There are several milestones to meet as seaweed becomes further recognized as a sustainable nature-based solution. Some of these projects are already materializing while others are initiatives that would fill current gaps.

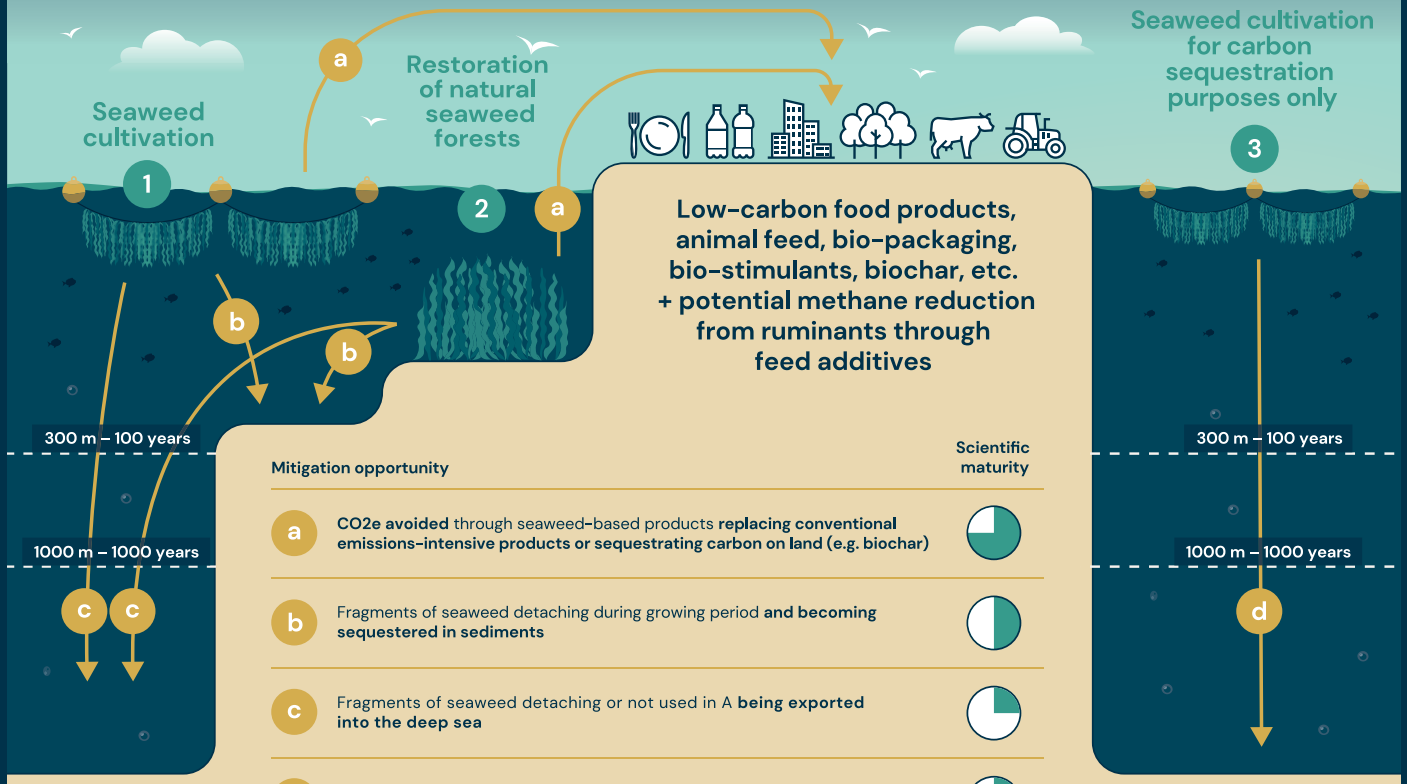
1. Measuring fate and transport of carbon from seaweed via different pathways.
2. Establishing the knowledge base to underpin carbon credit mechanisms.
3. Accrediting sustainable seaweed as a source of blue carbon sink among carbon verification bodies.
4. Promoting nature-positive regeneration of kelp and other seaweed ecosystems.
5. Implementing new seaweed-based food systems.
6. Attracting and enabling finance
7. Strengthening and further developing a scientific consensus and understanding of the many other ways seaweed can interact with the atmosphere.
8. Incorporating seaweed blue carbon into coastal and island nations' NDCs and NAPs under the Paris Agreement.

Seaweed as a nature-based climate solution

Did you know?

- Some seaweed species, such as Macrocystis pyrifera, can grow up to 50 cm per day in ideal conditions and to lengths of up to 60 m
- Seaweeds fix carbon at rates of between 1,000 and 3,400 grams per metre per year
- Current global natural seaweed forests could sequester roughly as much as the annual emissions of the United Kingdom and Egypt
- Seaweed is not only a nutritious and delicious source of food, but it also has a carbon negative footprint
- Evidence suggests, some seaweeds could reduce methane emissions from ruminants by up to 90 per cent if used as a feed additive
- In some regions, several thousand km² of seaweed forests have been lost over the past century

Multiple climate change mitigation opportunities offered by seaweed



Mitigation opportunity		Scientific maturity
a	**CO2e avoided** through seaweed-based products **replacing conventional emissions-intensive products or sequestrating carbon on land (e.g. biochar)**	
b	Fragments of seaweed detaching during growing period **and becoming sequestered in sediments**	
c	Fragments of seaweed detaching or not used in A **being exported into the deep sea**	
d	Intentionally sinking the macroalgae into the deep ocean, enabling it to be **sequestered long-term in the deep sea**	

Three ways to activate seaweed as a climate solution

	1 Seaweed cultivation	2 Restoration of natural seaweed forests	3 Seaweed cultivation for carbon sequestration purposes only
Key features	Seaweed cultivated and harvested to produce low-emission products	Restoration of wild seaweed forests	Seaweed grown for the primary purpose of sequestering carbon through deliberate sinking in the deep ocean
Business model	Seaweed product sales and, when available, from sale of carbon credits	Funded through public or philanthropic grants; carbon credits when available	Funded privately and from sale of voluntary offsets and, when available, carbon credits
Technical Maturity	Well established near shore but new (native) species still to be cultivated commercially	Increasing capability but challenges to ensure resilience to climate change	Technological and ecological questions remain to determine techno-economic affordability in offshore, exposed environments and the extent of carbon sequestration provided

VISION

THIS MOMENT CALLS FOR AMBITIOUS AND COLLECTIVE ACTION

The threats to human well-being from climate-change-driven impacts are now recognized to be more severe than was previously predicted 20 years ago and are already being felt today (IPCC, 2021). For many communities around the world, climate change is already an existential threat. United Nations Climate Change (2021) has warned that based on current trajectories, annual emissions of planet-warming greenhouse gas (GHG) emissions will have barely moved by 2030. The latest IPCC report highlights that — without immediate and rapid action — the world is heading for a temperature rise in excess of 3°C this century — far beyond the Paris Agreement goals of limiting global warming to well below 2°C and pursuing 1.5°C (IPCC, 2021).

In order for the world to avoid the more devastating impacts of climate change and be on track for a 1.5°C trajectory with no or limited overshoot, net global emissions will need to be cut by almost 50 per cent in the next decade and reach net-zero by around 2050 (IPCC, 2021).

The ocean, which has "absorbed between 20–30 per cent of anthropogenic CO2 emissions and over 90 per cent of the excess heat from human emissions" (IPCC, 2019), is disproportionately affected by climate change. Over the coming century, it is projected to experience continuing increased temperatures, substantially greater upper ocean stratification, further acidification, oxygen decline and reduced net primary production (IPCC, 2019).

The consequences are being felt around the world and the future impacts will be dire if current trends continue. Such changes are projected to precipitate a decline in global biomass of marine animal communities and fisheries, with knock-on effects for coastal communities dependent on healthy ocean ecosystems (IPCC, 2019).

The first priority remains rapid and deep decarbonization to get to zero emissions as quickly as possible.

However, in addition to eliminating GHG gases, between 100–1,000 gigatons of carbon removal will be required by the end of the century in order to meet the 1.5°C target with limited or no overshoot (IPCC Special Report 1.5, 2018).

This figure amounts to between approximately 2.5 and 25 years of humanity's current annual emissions (Global Carbon Project, 2020). Without carbon removal, even under the best emissions reductions' scenarios, there will be substantial risks, notably for food security, water resources, drought, heat exposure, coastal flooding and ecosystem and biodiversity loss. Continuing climate disruption will further compound social, regional and global inequalities.

The communities and groups that are most vulnerable to the impacts of climate change are often least responsible for the problem. Solutions for carbon sequestration include enhancing natural carbon sinks and developing a portfolio of carbon removal solutions in ways that are scalable, inexpensive, safe, socially just and sufficient.

SEAWEED AS A NATURE-BASED CLIMATE SOLUTION

Seaweed is arguably one of the most scalable nature-based solutions,[2] offering possibilities for both decarbonizing the economy and sequestering carbon from the surface of the ocean. As it grows in the sunlight zone of the ocean, seaweed fixes carbon through photosynthetic primary production. Seaweeds are excellent biomass producers that have rapid growth rates so that some species, such as Macrocystis pyrifera, can grow up to 50 cm per day in ideal conditions and to lengths of up to 60 m (Schiel and Forster, 2015). Some seaweed forests fix carbon at rates of up to ~3,000 grams per square metre per year (Gao & McKinley, 1994), making some species even more productive than tropical rainforests (Reed & Brzeinski, 2009). This rapid biomass production and carbon fixation rate can be harnessed to create valuable inputs that displace emissions from emission-intensive products and sequester carbon long term in ocean sediments and abyssal waters.

Decarbonizing the economy

Seaweed can help decarbonize the economy by replacing emissions-intensive products, including through low-carbon food, animal feed, fossil-based plastic replacements, fertilizers, fabrics and biofuels. For example, at present, methane from livestock currently represents around five per cent of annual GHG emissions (FAO, 2021). Some seaweed species have the potential to dramatically cut methane emissions from ruminant livestock when used as a feed additive for only a fraction of total feed supply. Harvesting and processing seaweed also enables potential land-based forms of sequestration (e.g. by serving as a soil additive). Seaweed can also be processed into land-based "carbon dioxide removal and storage-products" that remove CO_2 long term from the carbon cycle (e.g. biochar, bioenergy with carbon capture storage).

Carbon Sequestration

While seaweeds store carbon, their short lifespan means their primary contribution towards carbon sequestration is through "outwelling" biomass and its embedded carbon into sediments and the deep ocean (Krause-Jensen and Duarte, 2016; Santos et al., 2021). Seaweeds are continually shedding biomass as some vegetation constantly shed leaves.

During its growth phase, some seaweeds may fix as much carbon as is embodied in their structures. The different fates of the biomass determine carbon sequestration amounts and duration. Some of this biomass feeds ocean organisms, providing a food source for life under water, while some of it will sink into ocean sediment. A significant portion of coastal macroalgae is "outwelled" from the coast or carried out into the open ocean by ocean currents, where it sinks into abyssal waters, a process that has been likened to a "carbon conveyor". Once the biomass is sunk below 1000 meters, there is high certainty it will be sequestered for hundreds to thousands of years as it is removed from the ocean atmospheric carbon flux (Herzog et al., 2003; Krause-Jensen et al., 2018). Such processes occur in natural seaweed forests and are also provided by cultivated seaweed. Indeed, a 2016 study posited that at a rough global estimate, seaweeds sequester as much as 173 TgC yr–1, 90 per cent of which is through export to the deep sea (Krause-Jensen and Duarte, 2016), a figure roughly equivalent to the combined annual emissions of the UK and Egypt (Ritchie & Roser, 2020).

Unfortunately, in many regions of the world ranging from tropical to temperate waters, natural seaweed forests are threatened and in decline largely due to stress from ecosystem disruption, such as the removal of predators of the purple urchin, nearshore pollution and warming water temperatures, increased stratification and marine heatwaves from climate change. Moreover, many seaweed forests are migrating to colder waters and in the process losing some of their genetic diversity. This decline has disrupted vital ecosystem services, including carbon sequestration services, which would have been far greater pre-industrially and contribute to natural carbon sequestration. Without active interventions, seaweed forests that have been lost are unlikely to return.
The viability of seaweed cultivation in tropical countries is also being undermined by climate change. However, there is considerable potential to scale up seaweed cultivation, from the mere ~2,000 km^2 under cultivation today (Duarte et al., 2017), with several species demonstrating potential for large-scale cultivation including in exposed open ocean conditions.

Although some initiatives seek to cultivate seaweed purely for carbon sequestration, it should be noted that payments for carbon sequestration services are unlikely to be the main driver of the sector's growth in the near term which will instead be driven by the multiple economic uses of seaweed.

2. Nature-based solutions are defined using the IUCN standards framework.

MITIGATION OPPORTUNITIES OFFERED BY SEAWEED AS A NATURE-BASED CLIMATE SOLUTION

Seaweed offers four climate mitigation opportunities to accelerate deep and wide-ranging decarbonization and sequester carbon:

MITIGATION OPPORTUNITY	KEY FEATURES	SCIENTIFIC MATURITY Understanding and quantitation of the process and potential adverse effects
(A) Using seaweed products to accelerate decarbonization	CO_2e avoided through seaweed-based products replacing conventional emissions-intensive products or sequestering carbon on land through land-based CDR products (e.g. biochar[3])	▪ Full emissions lifecycle assessments of seaweed-based products are required to determine their potential for negative or avoided emissions ▪ Numerous existing carbon offset methodologies account for emissions reductions from bio-based inputs, which can potentially be adapted for seaweed-based products ▪ Seaweed as feed additive for ruminants, reducing methane emissions, is very promising but still being researched and tested to determine if this is safe and viable for climate mitigation
(B) Sediments	Fragments of seaweed detach during the growing period and become sequestered in sediments	▪ Presently being quantified, comprising a first step towards recognizing and accrediting seaweed forests and cultivation as substantial blue carbon sinks ▪ The exact carbon sequestration potential will vary depending on factors including species, location of the site and age and size of the farm
(C) Carbon Export	Fragments of seaweed detaching or not used in (A) being exported into the deep sea	▪ Further research is needed to examine how to track, monitor and potentially implement macroalgae for carbon storage on the sea floor to enable inclusion in carbon markets. Promising innovations are already underway to address such knowledge gaps[4]
(D) Deep Ocean Sequestration	Intentionally sinking the macroalgae into the deep ocean enabling it to be sequestered long-term in the deep sea	▪ Remaining issues to be addressed, including questions about the extent to which carbon is sequestered, potential for environmental consequences for the deep ocean, governance issues and the techno-economics of the activity at scale that may need to rely considerably on carbon credit revenues ▪ Further research needed to quantify, track and monitor macroalgae for carbon storage on the sea floor to enable inclusion in carbon markets ▪ Approaches that intercept and sink floating Sargassum can also apply and may qualify for an additional carbon offset from avoided emissions that would otherwise have arisen from decomposing beached Sargassum, although impact assessments should be conducted. ▪ Processing the seaweed biomass into recalcitrant end-products for deposition at the sea floor (e.g. biochar) may reduce possible harmful impacts ▪ This solution may outperform many land-based alternatives that face considerable competition for use and require greater resources

3. Examples of emissions-intensive produce include meat and plant foods, feed, biofuel, bioenergy carbon capture and sequestration (BECCS). It should be noted that some of these are more mature than others in terms of replacement.
4. For example, Bigelow Labs has a technology to measure carbon export in the water column by sugar kelp.

METHODS TO UNLOCK MITIGATION OPPORTUNITIES

There are three activation methods to unlock the four mitigation opportunities offered by seaweed.

	KEY FEATURES	BUSINESS MODEL	TECHNICAL MATURITY
(1) Restoration of Natural Seaweed Forests	Restoration of wild forests of seaweed, possibly with sustainable harvest	Funded through public or philanthropic grants or crowdfunding and, if available, from sale of carbon credits	▪ Increasing capability but challenges to ensure resilience to climate change (e.g. survival in warmer waters). This may require genomics work for effective restoration ▪ Challenges surrounding quantification of carbon sequestration from seaweed grown in exposed areas and additionality raises questions regarding the extent to which such measures will qualify for carbon credits
(2) Seaweed Cultivation	Seaweed cultivated (close to shore or offshore) and harvested to produce low-emission food, feed, packaging, fertilizers, etc.	Seaweed product sales and, when available, from sale of carbon credits	▪ Well established near shore but new (native) species still to be cultivated commercially. ▪ Technological questions remain to determine the techno-economic affordability of cultivating seaweed in offshore, exposed environments ▪ Need to create demand for higher value products to absorb the higher cost of supply from farms in the Global North
(3) Seaweed cultivation for carbon sequestration purposes only	Seaweed grown, most likely automated and offshore, for the primary purpose of long-term carbon sequestration through deep sea deposition while keeping logistical costs minimal	▪ Government investment needed for de-risking technology development ▪ Funded privately and publicly from sale of voluntary offsets and, when available, carbon credits	▪ Technological questions remain to determine the techno-economic affordability of cultivating seaweed in offshore, exposed environments ▪ Questions remain to determine the techno-economic viability, scalability and efficacy of this approach for carbon sequestration ▪ Possible ethical questions could be raised about sinking a nutritious food source in a context of global hunger

CO-BENEFITS OF SEAWEED AND OPPORTUNITIES FOR RESILIENCE

AS STATED IN THE SEAWEED MANIFESTO (2020), SEAWEED PRESENTS NUMEROUS OPPORTUNITIES BEYOND CARBON SEQUESTRATION, INCLUDING BUT NOT LIMITED TO:

1. Ripple Effects for Coastal Communities

Seaweed management or cultivation as well as its harvest and product processing is an opportunity to enhance rural livelihoods and coastal communities, especially in non-annex one coastal countries and Small Island and Developing States (SIDS). Combining production with processing also provides opportunities to create inclusive value chains and economic "pre-distribution" whereby economic benefits are widely distributed from the outset. Women are playing an important leadership role in the industry's development, particularly in developing countries. As has been widely demonstrated and evaluated in numerous case studies, the industry has contributed considerably to the empowerment of women in seaweed growing communities (Msuya and Hurtado, 2017). Seaweed cultivation also provides opportunities for livelihood transition, notably for commercial fishers who are facing occupational insecurity as fish stocks are depleted.

2. Enhancing Ocean Ecosystems & Resilience

Seaweed cultivation can provide climate adaptation benefits that help build in resilience, including temporary, localized refuge against increasing temperatures; acidification and deoxygenation; biodiversity enhancement; coastal protection and preventing soil erosion by attenuating wave energy from storms;[5] bioremediation services that improve water quality by excess-nutrient removal; and biodiversity enhancement through habitat provision. Strategically co-locating seaweed farms with Marine Protected Areas can maximize such benefits on biodiversity and fisheries. Characterizing lost fishery habitats and decimated fish populations is critical to understanding the potential of these nature-based solutions to restore lost fisheries through habitat and associated ecosystem services.

3. Enhancing Food Security & Building Resilient Food systems

Seaweed contributes directly to food security as a nutrient-rich food source and indirectly by enhancing agriculture by serving as an animal and aquafeed supplements and bio-stimulants for plants. Although the ocean covers 71 per cent of the earth's surface, it presently only contributes 2 per cent to the world's food supply on a caloric basis (FAO, 2018b), demonstrating that there are considerable scaling opportunities. Diversifying the food system can also help build in climate resilience to the possible impacts of climate change, such as drought. Seaweed cultivation can also contribute to food security by serving as a nursery to forage fisheries, thereby helping to rejuvenate fish stocks. Further benefits can be generated by systems that more efficiently use inputs to produce food and income, such as Integrated Multi-Trophic Aquaculture that combines seaweed cultivation with shellfish and/or finfish farming.

CHALLENGES

SEVERAL FACTORS MAY LIMIT THE EXPANSION OF SEAWEED AS A NATURE-BASED CLIMATE SOLUTION:

1. Monitoring possible ecosystem effects in the ocean

Natural seaweed beds and farms process carbon in complex ways. While significant data collection and modeling efforts are underway, more data and better understanding and modeling of system dynamics will be needed to accurately estimate net GHG drawdown by these systems under different scenarios (e.g. farm operation, seaweed product disposition). Approaches involving sinking large amounts of seaweed to the ocean seabed will have ecological and biogeochemical side-effects. Current understanding of the populations and interactions between the various organisms from the ocean is limited. There is significant risk that these impacts could be more negative than positive, emphasizing the strong need for field trials with effective monitoring in a variety of ocean basins and depths and with different species as a precursor to large-scale deployment. A proper risk assessment should accompany large-scale installations that aim to sequester carbon at scale using seaweed. Ecosystem monitoring should also be carefully undertaken.

5. From Duarte et al., (2017) For example, the canopies of farmed seaweeds, like those of wild seaweeds, dampen wave energy and hence, serve as live coastal protection structures buffering against coastal erosion (Mork, 1996; Løvås and Tørum, 2001)

2. Compelling communication to harness public support

Clear communication about seaweed's multiple climate benefits and the differences between the proposed approaches will be critical. There is also a need to emphasize that these approaches seek to either enhance or mimic natural processes. Finally, it should be stressed that under most conditions, seaweed is a source of "charismatic carbon", therefore carbon sequestration is only part of the seaweed story given the multiple other social and environmental benefits associated with seaweed cultivation. Emphasizing these benefits could help build strong social acceptance, particularly among coastal communities.

3. Current lack of cooperation and coordination

Multiple organizations, projects and efforts are underway to research, develop, characterize and document how seaweed can serve as a nature-based climate solution. Collaborating on these efforts in a coordinated way enables more to be accomplished coherently with less duplication of effort. International cooperation is especially needed given that the majority of the cultivation experience is in Asia and most of the initiatives to use seaweed for climate mitigation are in the Global North.

4. Accreditation of seaweed as a climate solution and source of blue carbon

Further development and innovation to enable monitoring, reporting and verification of carbon removal by seaweed forests and offshore farms is required. Doing so will enable the development of robust sustainability standards, accessible and affordable carbon verification systems and best carbon management practices to guide farmers, industries using seaweed products and consumers. Such science-based accreditation will help build the profile of seaweed as a nature-based climate solution to support the commercial operations of seaweed cultivation and help provide the funding and political support for seaweed restoration projects. Accreditation can also facilitate investment by climate-conscious investors, helping the industry scale to reach its potential as well as facilitate the inclusion of seaweed as a carbon sink in NDCs under the Paris Agreement.

5. Regulation and Governance

A. Institute regulation to reduce threats and better protect natural seaweed forests

Measures should be taken to mitigate some of the drivers of seaweed forest loss, such as trawling or excess pollution run-off, to help protect and potentially regenerate natural wild seaweed forests.

B. Streamlining regulation and permitting to facilitate a network of nearshore farms

Regulation and farm permitting needs to be streamlined and harmonized to alleviate competition for space with other ocean stakeholders nearshore, such as coastal communities, commercial shipping, commercial fishing, indigenous rights and marine protected areas, in order to accelerate progress. Highly productive regions not already in use by other stakeholders need to be identified and considered for priority access for seaweed cultivation. For countries that have yet to develop a permitting infrastructure to support seaweed cultivation, lessons can be learned from countries that have already created a substantial seaweed industry.

C. Governance and regulatory regimes that facilitate field trials to determine the full range of impacts of seaweed carbon sinking storage in the deep ocean

Clear governance frameworks are needed to enable accelerated field testing of approaches that sink seaweed for carbon sequestration and to ensure transparency, accountability and safety.

D. Agree on global policies and investment to support innovation for offshore cultivation

Significant expansion of the seaweed industry would very likely require substantial expansion into offshore and deep ocean environments. Challenges with expanding into offshore environments remain numerous, such as engineering of moorings and farm structures, challenges with operations and maintenance in distant and hazardous environments and the associated costs.

Most open ocean environments, with the exception of natural upwelling areas, will require nutrient supply to sustain macroalgal yields which may be technically challenging but feasible given other sectors' experience in offshore infrastructure. Harmonized frameworks for governance, regulation and investment will need to be established at various levels of government to facilitate development of offshore cultivation.

POLICY RECOMMENDATIONS AND BUSINESS AND SCIENCE ACTIONS

POLICY RECOMMENDATIONS

- Implement better protection and restoration of existing seaweed forests (e.g. through Marine Protected Areas, laws on agricultural run-off from land that impedes seaweed growth, trawling through seaweed sites, etc.).
- Support identification of highly productive areas for seaweed cultivation while accounting for existing coastal and offshore zoning plans (e.g. NOAA & MARINER effort underway for coastal United States[6]).
- Increase investment and streamline regulations for seaweed-based products that can help decarbonize the economy.
- Align regulatory standards through specific legislative direction to facilitate planning and permits that will encourage seaweed cultivation.
- Create an enabling regulatory environment to obtain licenses to operate and identify and allocate highly productive areas for seaweed cultivation in Marine Spatial Planning nearshore (Seaweed Manifesto, 2020).
- Incorporate an expansion of seaweed cultivation into national and multilateral development plans (e.g. the European Union targets pertaining to the expansion of seaweed and algae cultivation for human consumption in Mission Starfish).
- Acknowledge the importance of carbon dioxide removal to meet the objectives of the Paris Agreement within international agreements and provide simple frameworks to facilitate safe, responsible trials.
- Include the restoration of degraded kelp forests, establishment of new kelp forests and the expansion of seaweed cultivation in NDCs under the Paris Agreement.
- Include seaweed cultivation in island and coastal states' NAPs under the Paris Agreement to contribute towards natural disaster resilience.

RESEARCH AND DEVELOPMENT (R&D)

- Increase R&D into how to improve performance and reliability of commercially cultivated seaweed species.
- Increase investment into R&D for innovative seaweed products and biodiscovery of understudied and as yet cultivated seaweed species that could lead to climate mitigation through GHG displacement or carbon sequestration. Further R&D should be provided into upstream supply, processing (particularly lower carbon footprint approaches) and downstream economic uses of seaweed.
- Invest in human capital to help build the industry, ensuring that small scale producers that currently dominate global production are included in the industry's expansion.
- Conduct accelerated research efforts on the requisite engineering and scientific development needed to grow seaweed in the open ocean.
- Explore the possibility of safely increasing cultivable ocean area using novel means of accessing deep ocean nutrients.
- Conduct a series of transparent field trials to increase understanding of the potential of growing, sinking, tracking and monitoring seaweed for carbon sequestration in the deep ocean in order to determine the viability and safety of this approach.

SCIENCE

- Conduct further research into the environmental parameters that affect seaweed growth to improve cultivation and enable optimal identification of suitable cultivation sites.
- Improve the technology required for more efficient and affordable quantification of carbon stocks in blue carbon ecosystems and monitoring, reporting and verification.
- Assessment of the potential of developing blue carbon methodologies that account for the carbon sequestration services provided by outwelling of carbon from natural seaweed forests.

6. Please see: https://arpa-e.energy.gov/mariner-annual-review-2021

- Conduct science-based estimates of climate mitigation and ecosystem benefits of seaweed cultivation, including carbon sequestration potential under the different approaches. Derive estimates from in situ pilot studies where possible.
- Validate scientifically the long-term efficiency of using seaweed to reduce methane emissions from livestock and the absence of negative impacts on animal welfare and final product quality (e.g. milk, meat).
- Undertake and make accessible lifecycle carbon analyses of the major uses for seaweed biomass to understand the potential for negative or avoided emissions.
- Develop carbon offset methodologies that account for avoided emissions from seaweed-based products.
- Establish robust environmental safety standards. Develop clear risk assessment frameworks for ecosystem regeneration and for using seaweed to sequester meaningful amounts of carbon.
- Fund public and private actors to conduct accelerated research on the effects of sinking seaweed into the deep ocean, including monitoring and quantification of potential environmental impacts to better understand the possible ramifications of scaling. Initial trials can examine deep ocean canyons where seaweed is naturally outwelled to better understand the ramifications of enhancing this natural process.
- Improve high spatial resolution estimates of potential farmable ocean area, with recommendations for the optimal species to be grown in various locations.

FINANCE

- Increase public investment into seaweed related research, particularly with regard to its interaction with ocean ecosystems.
- Support the role of public funding and blended finance in de-risking investment in seaweed cultivation. Provide an incentive for seaweed farmers to target economic uses that reduce emissions (i.e. competitive seaweed carbon quotas).
- Consider a global seaweed area sponsorship programme, similar to reforestation programmes.
- Blue carbon payment systems to be put in place to remunerate seaweed farmers for the carbon sequestration services they provide.
- Create distributed finance mechanisms for artisanal small-scale seaweed farmers to be supported, which can be facilitated through digital platforms.
- Quantify and create markets to pay for seaweed's ecosystem services beyond carbon.

BUSINESS

- Accurately and effectively communicate the climate benefits, with consistent messaging that presents the various options seaweed can provide to mitigate climate change.
- Stimulate demand for use of seaweed products across different industries to help the industry scale. Comply with safety standards across regulatory areas, including environmental and social standards.
- Strengthen global collaboration and knowledge-sharing among seaweed stakeholders. The formation of regional seaweed coalitions and advocacy groups to identify and address bottlenecks may be key.
- Invest in the creation of new foods from seaweed (e.g. potential uses for dried seaweed powder or fermented seaweeds as key replacement ingredients).
- Increase community participation and connectivity across the value chain, enabling primary producers through digital ecosystem development.
- Facilitate business to community cooperation through investment, technical assistance and strategic value to strengthen new, and existing, cultivation operations and community organizations in developing countries.
- Continue to comply with a view towards harmonizing on safety standards across regulatory areas, including environmental and social standards.

REFERENCES

Duarte CM, Wu J, Xiao X, Bruhn A and Krause-Jensen D (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? Front. Mar. Sci. 4:100. doi: 10.3389/fmars.2017.00100

FAO (2018b).The state of world fisheries and aquaculture (Food and Agriculture Organization of the United Nations). Rome: FAO.

Msuya F.E. and Hurtado A.Q. (2017). The role of women in seaweed aquaculture in the Western Indian Ocean and South-East Asia, European Journal of Phycology, 52:4, 482-494, DOI: 10.1080/09670262.2017.1357084

Froehlich, H. E., Afflerbach, J. C., Frazier, M., & Halpern, B. S. (2019, August 29). Blue growth potential to mitigate climate change through seaweed offsetting. Current Biology. https://www.sciencedirect.com/science/article/pii/S0960982219308863.

Global Carbon Project, (2020). Supplemental data of Global Carbon Budget 2020 (Version 1.0) [Data set]. Global Carbon Project. https://doi.org/10.18160/gcp-2020

Gao, K., McKinley, K.R. (1994). Use of macroalgae for marine biomass production and CO2 remediation: a review. J Appl Phycol 6, 45–60. https://doi.org/10.1007/BF02185904

Herzog, H., K. Caldeira, and J. Reilly. (2003). An issue of permanence: Assessing the effectiveness of temporary carbon storage. Climatic change 59:293-310.

IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Santos, I., Burdige, D., Jennerjahn, T., Bouillon, S., Cabral, A., Serrano, O., Wernberg,T., Filbee-Dexter, K., Guimond, J., Tamborski., J (2021) The renaissance of Odum's outwelling hypothesis in 'Blue Carbon' science. Estuarine, Coastal and Shelf Science, Volume 255, 107361,ISSN 0272-7714, https://doi.org/10.1016/j.ecss.2021.107361.

Krause-Jensen D, Lavery, P., Serrano O, Marba, N. Masque, P, and Duarte, C. (2018) Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. BioL .Lett. 14: 20180236. 20180236. http://doi.org/10.1098/rsbl.2018.0236

Reed, D.C. and Brzezinski, M.A. 2009. Kelp forests. Pp. 31–37. In Laffoley, D. and Grimsditch, G. (eds), The Management of Natural Coastal Carbon Sinks. IUCN, Gland, Switzerland.

Ritchie, H. and Roser, M. (2020). CO_2 and Greenhouse Gas Emissions. Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource]

UNFCCC (2021, February 26). NDC Synthesis Report. unfccc.int. https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs/ndc-synthesis-report#eq-5

UN Global Compact (2020) Seaweed Manifesto. Available: http://www.seaweedmanifesto.com/

UN Global Compact (2021) Practical Guidance for the UN Global Compact Sustainable Ocean Principles: Seaweed. Available: https://ungc-communications-assets.s3.amazonaws.com/docs/publications/UN%20Global-Compact-Sustainable-Ocean-Principles-Seaweed.pdf

SUGGESTED FURTHER READING

- The Energy Futures Initiative wrote a 2020 report examining marine-based CDR strategies in which seaweed was described as one of the most promising solutions (table comparing different strategies on pages 15–16. https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/6011a63f65321405af54681f/1611769420810/Uncharted+Waters.pdf.pdf
- ClimateWorks Foundation has written a primer on marine-based CDR solutions where the potential of seaweed cultivation was also prominent (summary of seaweed for CDR on page 16) https://www.climateworks.org/wp-content/uploads/2021/02/ClimateWorks-ocean-CDR-primer.pdf
- Seaweed for Europe (2020). Hidden Champion Report. Available Online: https://www.researchgate.net/publication/337198669_Investing_in_nature-based_actions_and_seaweed_farming_one_of_the_five_opportunities_to_make_the_Ocean_part_of_the_solution_to_climate_change
- Ocean Visions Roadmap
https://oceanvisions.org/roadmaps/r-cultivation-carbon-sequestration/state-of-technology/#overview

THE TEN PRINCIPLES OF THE UNITED NATIONS GLOBAL COMPACT

HUMAN RIGHTS

1 Businesses should support and respect the protection of internationally proclaimed human rights; and

2 make sure that they are not complicit in human rights abuses.

LABOUR

3 Businesses should uphold the freedom of association and the effective recognition of the right to collective bargaining;

4 the elimination of all forms of forced and compulsory labour;

5 the effective abolition of child labour; and

6 the elimination of discrimination in respect of employment and occupation.

ENVIRONMENT

7 Businesses should support a precautionary approach to environmental challenges;

8 undertake initiatives to promote greater environmental responsibility; and

9 encourage the development and diffusion of environmentally friendly technologies.

ANTI-CORRUPTION

10 Businesses should work against corruption in all its forms, including extortion and bribery.

The Ten Principles of the United Nations Global Compact are derived from: the Universal Declaration of Human Rights, the International Labour Organization's Declaration on Fundamental Principles and Rights at Work, the Rio Declaration on Environment and Development, and the United Nations Convention Against Corruption.

ABOUT THE UNITED NATIONS GLOBAL COMPACT

As a special initiative of the UN Secretary-General, the **United Nations Global Compact** is a call to companies everywhere to align their operations and strategies with Ten Principles in the areas of human rights, labour, environment and anti-corruption. Our ambition is to accelerate and scale the global collective impact of business by upholding the Ten Principles and delivering the Sustainable Development Goals through accountable companies and ecosystems that enable change. With more than 13,000 companies and 3,000 non-business signatories based in over 160 countries, and 70 Local Networks, the UN Global Compact is the world's largest corporate sustainability initiative — one Global Compact uniting business for a better world.

For more information, follow **@globalcompact** on social media and visit our website at **unglobalcompact.org**.

United Nations
Global Compact

685 Third Avenue New York, NY 10017, USA