2021 United Nations Decade
2030 of Ocean Science
for Sustainable Development

SEAFORESTATION:

BENEFITS TO THE CLIMATE, THE ECOSYSTEMS, AND THE PEOPLE OF BRITISH COLUMBIA

OCEAN WISE

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Acknowledgment

This report was written and published on the traditional, ancestral, and unceded lands of the xʷməθkʷəy̓əm (Musqueam) Sḵwxwú7mesh (Squamish), and səlilwətaɬ (Tsiliel-Wuatuth) Peoples.

We acknowledge that our work spans across the lands of many Indigenous Peoples. As the Seaforestation program develops, we understand that collaborating with Indigenous communities and intertwining Indigenous ways of knowing into our work is essential to decolonizing ocean conservation and realizing the full spectrum of benefits to people, the land, and the ocean.

"Natural climate solutions have the potential to tackle both climate mitigation and adaptation challenges at relatively low-cost while providing co-benefits for people and nature"

– Canada's 2030 Emissions Reduction Plan

EXECUTIVE SUMMARY

Devastating fires, fatal flooding, and shattered temperature records. These climate events in British Columbia make abundantly clear the need for innovative solutions that reduce the amount of carbon in the atmosphere, but which also increase the resilience of communities and ecosystems to the impacts of climate change. Canada's 2030 Emissions Reductions Plan alongside Canada's Strengthened Climate Plan and British Columbia's Clean BC Roadmap to 2030 collectively call for investment into nature-based solutions that capture and sequester carbon to help meet Canada's commitment to Net-Zero by 2050. To be successful we must use science and evidence based decision-making to determine which solutions offer the greatest opportunity to meet these targets. This report aims to apply this lens to identify the benefits that seaforestation can offer to the climate, the ecosystems, and people of British Columbia.

Nature-based climate solutions have now been widely adopted into climate strategies by governments around the world, including the 2 billion trees commitment made by Canada in 2020. Until recently, the potential of seaweed to sequester carbon has been overlooked in the arsenal of nature-based climate solutions. However, emerging research places seaweed as a powerful and scalable solution, offering carbon drawdown alongside various co-benefits.

Seaforestation – the restoration, planting, management, and care of underwater seaweed forests – is a climate solution that presents multiple pathways for removing carbon dioxide from the atmosphere while improving the health of ocean ecosystems, contributing to community food security, and creating environmentally focused jobs in British Columbia.

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This report examines and summarizes the multitude of benefits that would accompany the expansion of seaforestation in British Columbia. We present new data on the abundance and distribution of natural kelp forests in the province, estimating how much carbon is absorbed and further sequestered. We then outline three pathways to maximize the benefits of seaforestation. We conclude with a summary of urgent applied research questions that need to be answered and propose ten actions and policy recommendations that could help to bring seaforestation to scale in British Columbia.

Key Findings:

Climate Change Adaptation:

Naturally occurring kelp forests have already seen significant declines in British Columbia due to human induced pressures, including climate change. Adaptation to warming ocean temperatures will require the protection and restoration of kelp forests to foster flourishing marine habitats, while seaweed cultivation can create more resilient economies and food systems for coastal communities.

The biodiversity supported by kelp forests provides roughly $2.1 billion dollars in potential value to fisheries each year

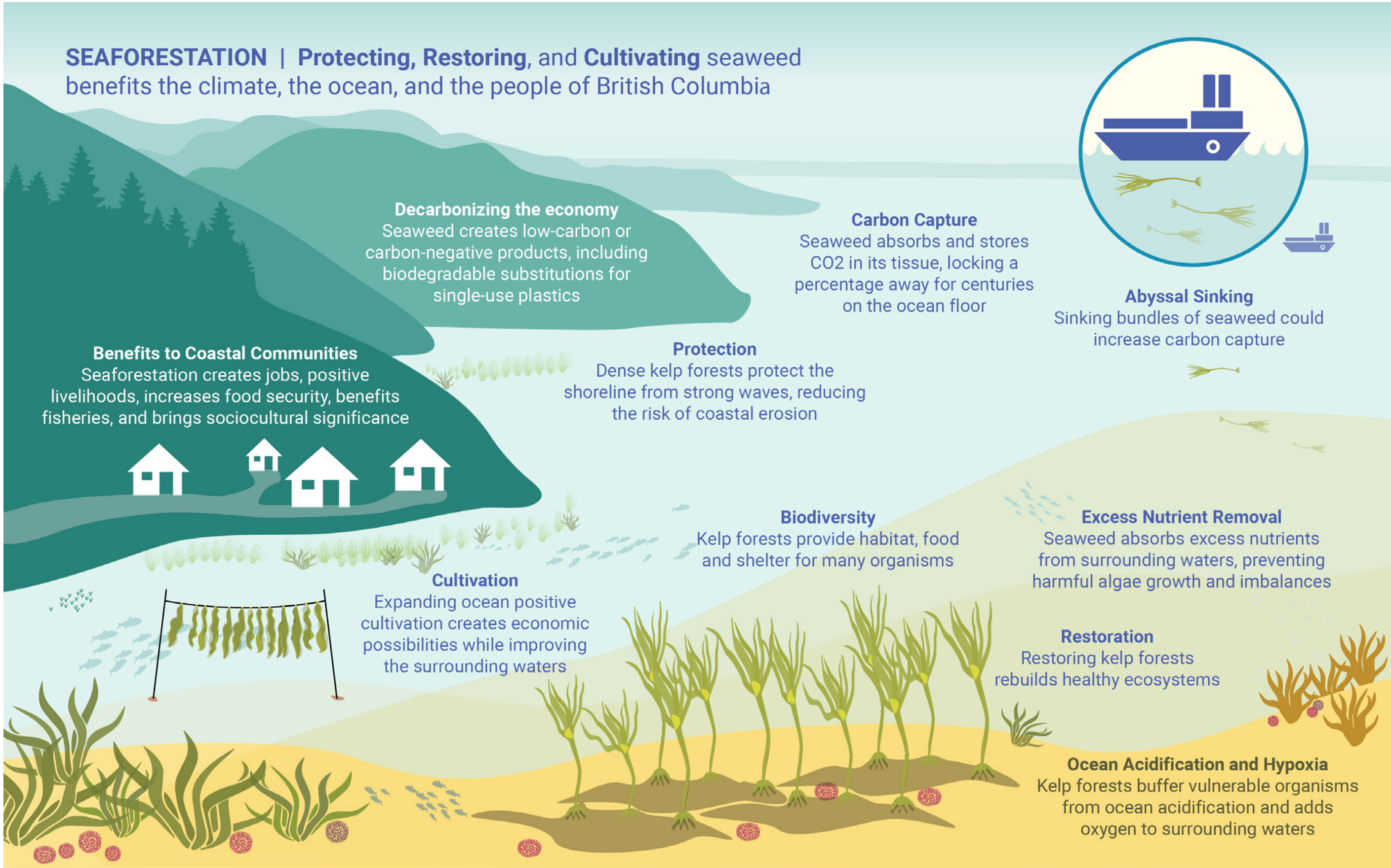
- Kelp forests are integral in supporting high levels of biodiversity in British Columbia's waters, forming crucial habitat for species at risk such as sea otters and northern abalone. Healthier, abundant ecosystems are more resilient ecosystems.
- The biodiversity supported by kelp forests provides roughly $2.1 billion dollars[1] in potential value to fisheries each year. Fisheries reliant on kelp habitat see their resilience strengthened if the vulnerability of kelp forests to anthropogenic stressors is reduced.
- Kelp forests buffer vulnerable species from the impacts of ocean acidification and hypoxia, help clean the water by absorbing excess nutrients, and protect coastlines by dampening waves.
- Cultivating seaweed has significant implications for creating climate resilient food systems that can provide protein and nutrients as land availability and crop growth are impacted by a changing climate.

Climate Change Mitigation and Carbon Removal:

Seaforestation provides a powerful and scalable opportunity to mitigate both carbon and methane emissions:

- British Columbia hosts at least 190 km^2 of canopy-forming kelp beds along the coastline of the province. Our estimate shows that these kelp beds sequester at least 7,755 tons of CO_2 per year - the equivalent emissions of heating 3,900 homes in B.C. using natural gas.
- Products such as bioplastics, agricultural fertilizers, and biofuels can be synthesized from seaweed: avoiding emissions by offering lower carbon footprint alternatives.
- Products such as seaweed enriched cattle feed can reduce methane emitted from cattle by 40-90% and greatly contribute to Canada's emission reduction goals.
- Urgent research must be undertaken to explore the carbon removal potential and environmental impact of the practice of abyssal sinking – sequestering carbon in seaweed biomass by sinking it in the deep sea where decomposition is significantly slowed down.

1 All dollar values are in CAD (2021) unless otherwise indicated



Economic Opportunity:

Bringing seaweed cultivation and restoration to scale will create jobs and open opportunities for new industries to meet the demands of a decarbonizing world.

Bringing seaweed cultivation and restoration to scale will create jobs and open opportunities for new industries to meet the demands of a decarbonizing world.

- Expanding seaweed cultivation in British Columbia can create thousands of environmentally focused jobs in coastal communities.
- The global seaweed industry is expanding rapidly and was valued at USD $11.5 billion in 2020 with an annual growth rate projected at 11.8% from 2021 to 2026.
- Planting trees have a lower associated cost per tonne of carbon sequestered over relatively short time periods than kelp forest restoration; however, kelp forests have higher economic value, no risk of loss due to fire, greater co-benefits to surrounding ecosystems and generates substantive sequestration year after year over decades, unlike mature tree forests which tend to plateau over time. This results in a sustained carbon-trading opportunity.
- Seaweed cultivation scenarios that set aside between 10-40% of yield to be sequestered still recover initial costs through yearly profits, making these ocean-positive scenarios attractive for kelp farmers, government, and local communities.

Recommendations

In order to realize the climate change adaptation and mitigation potential alongside the economic opportunities presented through the responsible expansion of seaforestation in British Columbia, we recommend the following actions:

- Invest in the research and development of seaforestation techniques to responsibly take them to scale and maximize environmental, economic, and social returns.
- Invest in a site-selection protocol for seaforestation interventions that is climate-proof and maximizes environmental, economic, and social returns.
- Socialize opportunities and incentives with rightsholders and stakeholders.
- Create financial incentives and investment schemes, as well as regulatory adjustments, for the responsible expansion of kelp, both for cultivation and restoration, while monitoring impacts and efficacy of seaweed projects at delivering environmental, economic and social benefits.
- Implement better mapping, monitoring, and protection of existing kelp forests.
- Create a seed bank to preserve the genetic diversity of seaweeds in British Columbia.
- Identify kelp strains with stress resistant properties and assess their potential to restore areas decimated by marine heat waves.
- Add the climate services that the expansion of seaweed can provide to the projected national carbon balance, by accounting for carbon drawdown in restored and cultivated seaweed.
- Prioritize and fund ocean & climate literacy programs to expand the awareness of the citizenry about the role of healthy oceans in the fight against climate change, as well as to inspire, empower and equip citizens to take ocean-positive action.

CLIMATE CHANGE: A CALL TO ACTION

In 2021, the planet's surface temperature averaged 1.1°C above pre-industrial levels.[1] At just over 1°C of warming, British Columbia is already experiencing an unprecedented series of climate events. In 2021 alone, the forest fire season burned over 8,500 km^2 of land – a quarter of the size of Vancouver Island – and a heat dome shattered national temperature records in the province. That same year, autumn flooding events destabilized the province's food and fuel supplies, displaced thousands of people, and caused severe damage to key transportation and agricultural infrastructure.

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The Intergovernmental Panel on Climate Change (IPCC) has warned that, based on current greenhouse gas emission trajectories, Earth is potentially on track to see an average temperature increase of 3°C this century, unless drastic measures to reduce greenhouse gas emissions are put in place.[2] Through emissions targeting, governments of the world are attempting to realize a planet that stays under 1.5°C warming. It is now understood that there is no "silver bullet" solution to climate change; necessitating the application of multiple, diverse strategies to draw carbon from the atmosphere and create resilient communities and ecosystems.

Earth – the blue planet – is covered by over 361 million square kilometers of ocean, equating to approximately 70 per cent of the planet's surface.[3,4] The ocean represents 99 per cent of the living space on the planet by volume.[5] Despite its great vastness, the ocean is not immune to the effects of climate change and is disproportionally affected by changes in temperature and carbon dioxide (CO_2) concentrations. The ocean acts as an important buffer from climate impacts having absorbed 20-30 per cent of anthropogenic CO_2 emissions and over 90 per cent of the excess heat from human emissions.[3] However, the ocean is not only critical for carbon absorption. Over 3 billion people rely on the ocean to make a livelihood while billions more rely on the ocean for food, resources, and critical ecosystem services. Locally, ocean-oriented activities such as tourism, transportation, and fishing contribute $17 billion annually to British Columbia's economy and employ over 170,000 people.[6]

While reducing greenhouse gas emissions is the most important method of limiting planetary warming, most of the pathways described by IPCC for limiting warming below 1.5°C and 2°C are heavily reliant on the removal of carbon dioxide from the atmosphere. The International Energy Agency states that meeting our 2050 goals will become virtually impossible without both natural and engineered carbon capture and sequestration, with the need to sequester 190 times the quantity of carbon that is currently removed from the atmosphere.

Blue Carbon – the absorption and storage of carbon by coastal and ocean ecosystems – has only recently gained the attention of governments and policymakers. Coastal ecosystems such as mangroves, eelgrass, and saltmarshes make up the majority of current Blue Carbon strategies;[7] however, the importance of seaweeds for their potential in climate change mitigation has been largely overlooked.[8] Recent studies indicate that seaweed is responsible for absorbing and sequestering millions of tonnes of CO_2 each year through the movement of tissue away from the coast and into the deep sea.[8]

Kelp forests can be found growing along polar and temperate coastlines around the world, from Greenland to Australia. In British Columbia, they are naturally abundant and offer a scalable pathway to absorb and sequester substantial amounts of carbon – greatly contributing to achieving Canada's Net-Zero emissions targets. In addition to its role in carbon storage, expanding kelp cultivation and restoration in British Columbia has the potential to contribute to ocean health and food security while creating environmentally focused jobs for British Columbians.

Beneath the crashing waves of British Columbia's emerald sea, towering kelp forests form the foundations of a bustling and biodiverse ecosystem.

Seaweed is a broad term that refers to a diverse group of marine algae, which come in all shapes and sizes, from microscopic phytoplankton to towering forests of giant kelp. When describing seaweed in the context of human use, the term refers to medium and large species or macroalgae. There are three distinct groups of seaweed: Red (*Rhodophyta*), Brown (*Phaeophyta*), and Green (*Chlorophyta*) algae.

The term *kelp* refers to a subset of large, brown seaweeds that thrive in subtidal areas, on rocky substrate, and where nutrients are abundant.[9] Kelp are often called *"the sequoias of the sea"* as they occupy similar ecosystem roles in the ocean as trees do in a forest. Like trees, kelp are photosynthetic – meaning they use solar energy to convert CO_2 into organic matter, releasing oxygen (O_2) in the process. This ability to turn sunlight into energy places kelp in a foundational role of primary producer, providing vegetative food for herbivores such as sea urchins.[10] Animals at higher levels in the food chain, such as the carnivorous sea otter, eat the urchins, while they themselves are predated upon by larger marine mammals. This food chain converts and transfers solar energy from kelp all the way to killer whales, providing an important foundation for British Columbia's coastal ecosystems. A significant amount of the carbon found in many coastal animals can be traced back to kelp-originating carbon.[11]

Unlike trees, kelp do not have roots. Instead, they grow holdfasts which allow them to attach to rocks on the sea floor and prevent them from floating away. Many species of kelp, such as bull kelp (*Nereocystis luetkeana*) have buoyant bulbs that pull kelp towards the surface of the ocean, maximizing the sunlight available for photosynthesis.[12]

Kelp stand out from other types of seaweed due to their size and growth rate. Individual kelp plants of the species giant kelp (*Macrocystis pyrifera*) can reach up to 45 m in height and grow at an incredible rate of 30 cm (1 ft) per day in the ocean, making them one of the fastest growing organisms on the planet.[14] The high productivity of kelp is partially due to their ability to fix carbon in the absence of sunlight, as well as to store nitrogen for use when there is a deficit of nutrients in their surroundings.[13]

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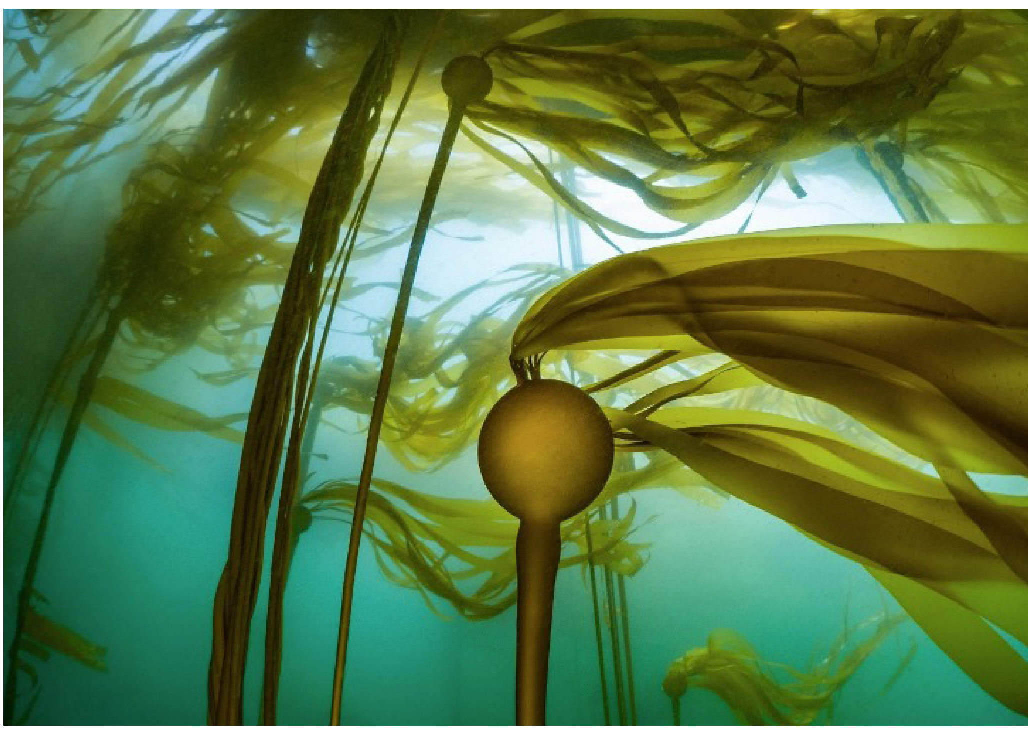

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HOW DOES SEAWEED BENEFIT PEOPLE?

Humans have been tied to seaweed for millennia. The "Kelp Highway Hypothesis" suggests that the first inhabitants of the Americas may have followed kelp beds along pathways to new lands.[14] For many coastal Indigenous Peoples in the Pacific Northwest, much traditional ecological knowledge surrounds kelp and its important role in sustenance, stories, and symbolism.[14] In our rapidly changing reality, seaweed will play an increasingly important role decarbonizing the economy, stimulating economic activity and fostering food security for coastal communities.

Food

Seaweeds are protein rich foods high in fiber, vitamins, and minerals that can deliver a variety of health benefits.[15] On its own, seaweed can be eaten raw, cooked, dried, or powdered and is widely used in many cuisines around the world.[15] Some seaweeds are the source of the compound alginate, which is routinely used as a thickener, stabilizer, and gelling agent in the manufacture of foods such as ice cream, pharmaceuticals, and cosmetic products.[16]

Seaweed does not compete with other crops for agricultural land, which has substantial implications as the climate changes and terrestrial land-use pressures increase. Kelp forests provide the foundations of an ecosystem home to important species that are integral to the food sovereignty[ii] of many communities. They support nursery habitats for species such as Pacific herring, salmon, and rockfish which support the fisheries so many around the world rely upon.[17] The ecosystem services that kelp forests provide have been poorly understood, and only recently have they been assigned a monetary value.[18] It is estimated that British Columbia's existing wild kelp forests are worth upwards of $2.1 billion per year for their contributions to the potential economic value[iii] of fisheries in the province.[18, iv]

ii Food Sovereignty - The right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods.

iii Potential economic value to fisheries includes species with current harvesting closures, such as Northern Abalone.

iv Calculated from numbers by Eger et al., pre-print, 2020

Decarbonizing the economy

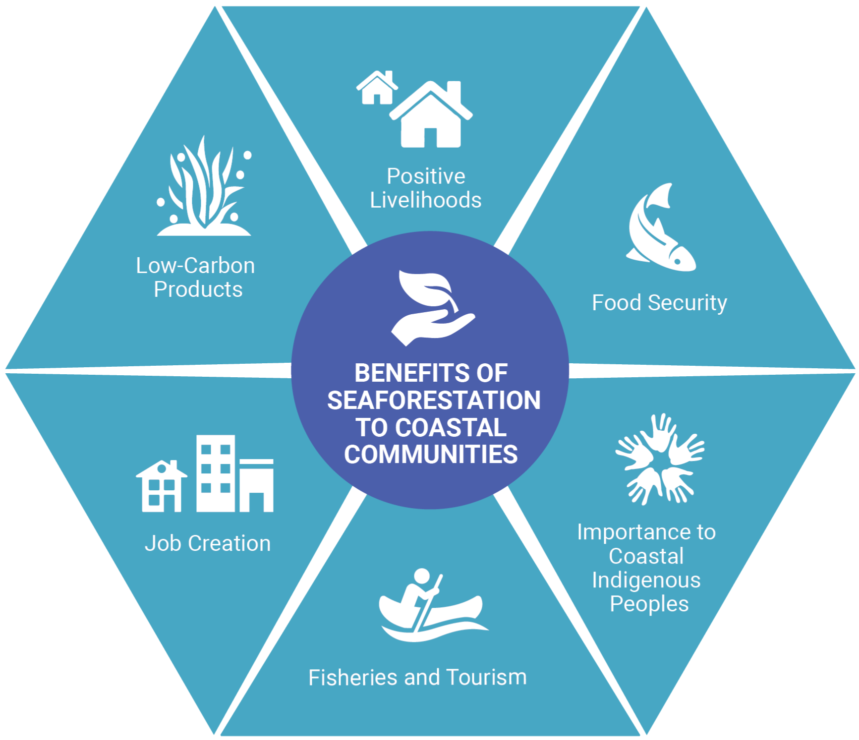
Between 2005 and 2015, global seaweed production doubled from 14.7 million tonnes to 30.4 million tonnes, resulting in a global seaweed industry worth $11.5 billion USD in 2020 with an annual growth rate projected at 11.8% from 2021 to 2026.[19,20,21] The expansion of the global seaweed industry creates an economic opportunity in British Columbia.

Seaweed-based innovations, coupled with investment in green economies, forecast a rapidly expanding market for low-carbon products. Prototypes for seaweed-based textiles, antimicrobial bandages, biofuels, and biodegradable plastic alternatives are actively being researched and production has already begun on a small scale.[16,22,23,24] These innovations offer alternative products with much smaller carbon footprints. For example, cultivating one square kilometer of seaweed to create biofuel has the potential to avoid about 1,500 tons of CO_2 every year when compared to emissions from fossil fuel use.[24] The production of seaweed for food is much less emissions-intensive than food production in land-based systems.[24]

"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."

– UN Global Compact, 2021

Seaweed can also be used as an effective, inexpensive organic fertilizer that offers environmental benefits along its life cycle – by offsetting the use of energy intensive, non-organic fertilizers.[23] In the context of the 2022 global fertilizer shortages, locally sourced fertilizers can greatly contribute to resilient food systems in Canada.



Additionally, current research suggests that adding seaweed to cattle feed can significantly reduce methane emissions. The inclusion of red seaweeds in cattle feed has shown a 90 per cent reduction in enteric[v] methane production[25,26] and brown seaweed species have shown up to a 40 per cent reduction.[27] Additional research is needed to validate the long-term efficacy of this method; however, during the COP26 conference, Canada pledged to reduce methane emissions by at least 30 percent by 2030.[28] The agricultural sector creates 29 per cent of Canada's methane emissions,[37] meaning seaweed could play a substantial role in helping Canada meet its methane targets if this avenue is properly explored and incentivized.

Job Creation

The expansion of seaweed industries in British Columbia has the potential to create thousands of environmentally focused jobs in coastal communities – many of which have been deeply affected by declining fish stocks and market complications from the COVID-19 pandemic. Kelp forest restoration and wild harvest opportunities can provide other forms of income for communities at a time when alternatives are limited. Cascadia Seaweeds estimates that seaweed farming has the potential to generate 30,000 jobs and over $1 billion to the GDP of coastal British Columbia.[30,31]

v Enteric methane – methane produced during the digestive processes of ruminants (ei. cows, sheep, goats)

HOW DOES SEAWEED BENEFIT THE OCEAN AND THE CLIMATE?

The ability of seaweed to convert CO_2, sunlight, and nutrients into food and habitat for other animals while releasing oxygen into the surrounding waters provides numerous benefits to the ocean, the atmosphere and humanity.

Carbon drawdown and sequestration

While photosynthesis is conducted by many other organisms on earth, seaweed's substantial growth rate results in the generation of large amounts of tissue in short periods of time. Globally, the tissue generated during this growth absorbs billions of tons of carbon from the ocean every year.[8] This absorbed carbon is then replaced by carbon from the atmosphere to balance off the difference in dissolved carbon cre [61] ated by growing kelp tissue. The result is CO_2 drawn down from the atmosphere.

... around 11 per cent of the carbon absorbed during the growth of naturally occurring seaweed populations is sequestered in ocean sediment, which represents a vast amount of carbon both regionally and globally

It is important not to confuse the amount of carbon absorbed with the amount of carbon permanently sequestered each year, as much of this absorbed carbon quickly re-enters the carbon cycle when fronds break off and decay. Permanence refers to the long-term removal of carbon from the atmosphere for hundreds of years – or a length of time great enough to help mitigate climate change.

For seaweed to contribute to carbon sequestration for a timeline relevant to climate change, the carbon must be buried in marine sediment nearby or exported away from the seaweed bed and sequestered in the sediment of the deep sea.[8] There are many variables that can affect the sequestration potential of kelp forests such as currents, coastal geography, characteristics of seaweed species, and oxygen content. Current research estimates around 11 per cent of the carbon absorbed during the growth of naturally occurring seaweed populations is sequestered in ocean sediment, which represents a vast amount of carbon both regionally and globally.[8] An evaluation of Australia's kelp forests suggests they sequester 4.8-10.3 million tonnes of CO_2 per year, which accounts for more than 30% of the blue carbon stored around the continent.[32] Additionally,

seaweed offers above-water carbon sequestration if converted into products such as building materials, bioplastics, or biochar. These solutions are discussed further in this report.

Unlike the sequestration pathways of other ecosystems such as forests, mangroves, or wetlands the natural carbon sequestration from kelp often transports the carbon kilometers away from the source and into deep sea sediment.[33] While this makes the sequestration of kelp more difficult to quantify, it also results in carbon that is protected from disturbances such as forest fires, coastal erosion, development, or other stressors. Forest fire risk is already increasing dramatically throughout the 21st century, meaning that some forests could turn from net carbon sinks, into net carbon sources.[34] Indeed, the Amazon rainforest is already a net source of atmospheric carbon due to degradation from climate pressures and continued deforestation.[35] While kelp forests and the carbon stored within are vulnerable to climate impacts like warming oceans, the carbon they sequester in deep sea environments is not.

However, it is important to highlight several knowledge gaps in our understanding of seaweed carbon sequestration pathways, and their efficacy for large-scale climate mitigation. More research must be conducted to (1) understand pathways to deep sea sequestration and their dependency on local oceanographic conditions, (2) understand better the complex CO_2 exchange between the ocean and the atmosphere, and (3) evaluate the true additionality of seaweed forest carbon removal when compared to the ecosystems they replace, among other gaps.[36,37] While it is prudent not to over-promise the carbon sequestration potential of seaweeds, until the gaps in our scientific knowledge are filled, the numerous additional benefits of seaweed create a no-regrets scenario for the expansion of seaforestation in British Columbia.

Biodiversity

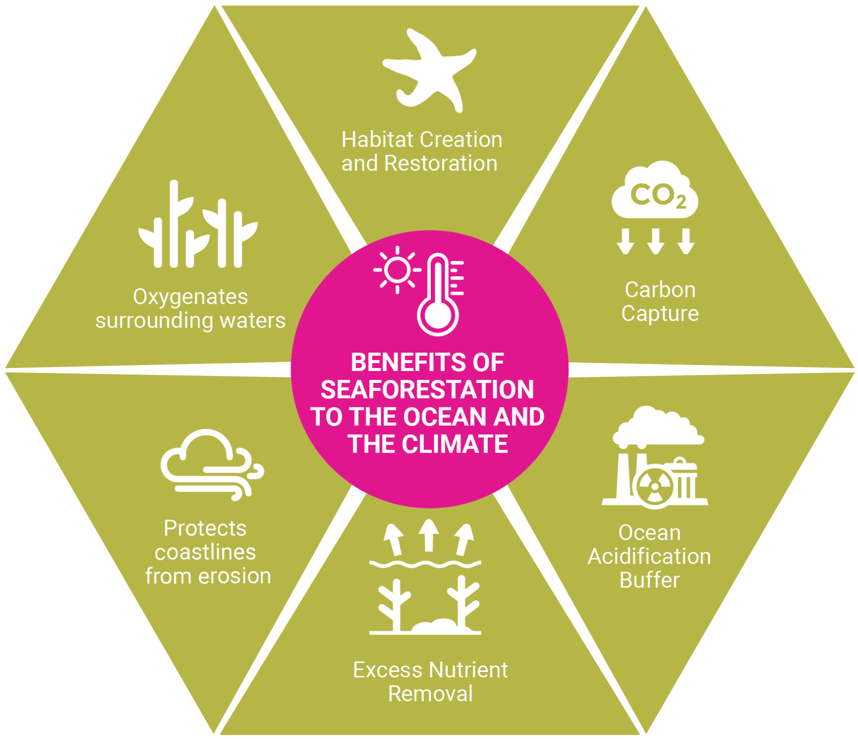
Much like terrestrial forests, kelp forests provide habitat, shelter, and food for a multitude of ocean organisms – forming the foundation for an ecosystem that fosters high levels of biodiversity.[10] The dynamic structure of kelp forests create crucial habitats for several species identified under the Canadian Species at Risk Act (SARA), including sea otters (*Enhydra lutris*), northern abalone (*Haliotis kamtschatkana*), and yellow-eyed rockfish (*Sebastes ruberrimus*).[38,39] In the upper column of kelp forests, sea otters grab hold of kelp blades for stability while Pacific herring – a forage fish that makes up the diet for salmon, sea lions, and many other species – lay millions of eggs on the broadleaves of the forest.[40] Without kelp as ecosystem engineers, the equilibrium and structure of these systems would dramatically change, and potentially cease to exist altogether,[53,54] threating the abundance of a multitude of species along the coast of British Columbia. This, in turn, has economic impacts on livelihoods reliant on kelp-associated species.

Kelp plays a vital role in capturing excess carbon in the water, releasing oxygen – consequently reducing the acidity and increasing the oxygen content of the surrounding waters, particularly in the upperwater column.

Ocean Acidification and Hypoxia

The increase in greenhouse gas emissions from human activity has also resulted in more dissolved CO_2 in the ocean[42] – a phenomenon that is causing ocean acidification. Ocean acidification refers to a decrease in pH[vi] of the ocean, which can be detrimental to the survival of many organisms, especially those that create shells or exoskeletons such as crabs, sea urchins, mussels, and corals.[42] Additionally, many coastal ecosystems suffer from hypoxia – or oxygen depletion, which can impact the health of many organisms. Kelp plays a vital role in capturing excess carbon in the water, releasing oxygen - consequently reducing the acidity and increasing the oxygen content of the surrounding waters, particularly in the upper water column.[57] Kelp can therefore provide a buffer to animals not yet adapted to more acidic ocean ecosystems by creating localized micro habitats with varying levels of pH and delaying the consequences of changes in ocean chemical composition.[43]

vi pH – the measure of how acidic or basic a solution is. The lower the pH, the more acidic the water.

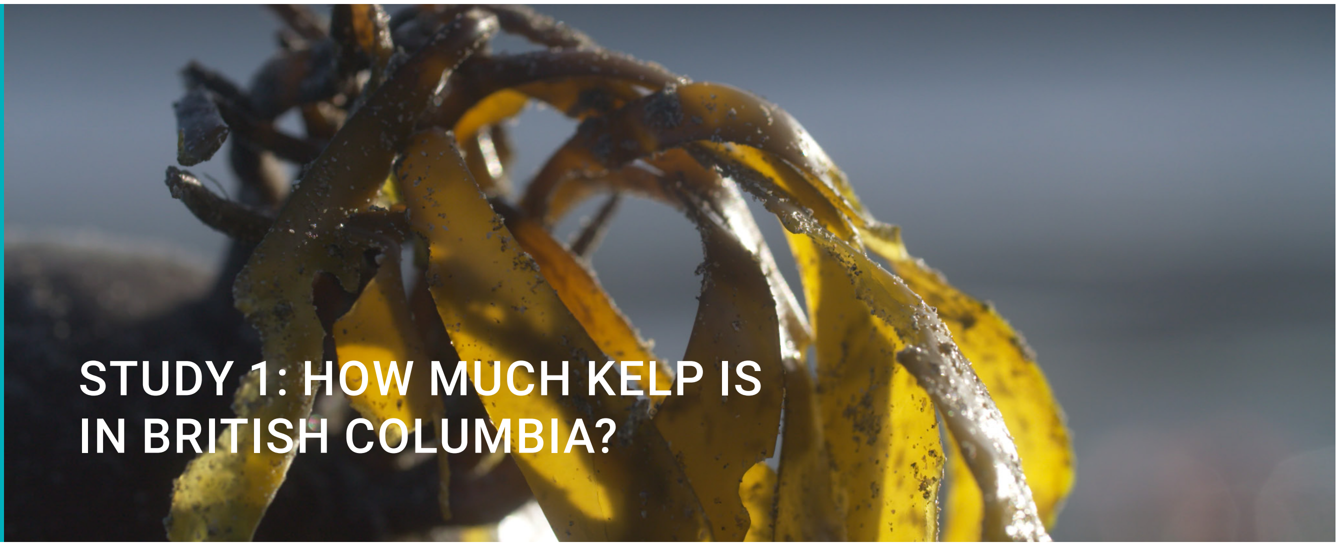


Wave attenuation

Dense kelp forests absorb energy from strong wave action, attenuating their impact on the shores and protecting coastlines from erosion and flooding. Larger areas of healthy kelp forests have been shown to have greater potential for calmer coastal habitats.[44,45] This is particularly relevant as we adapt to a climate impacted world with an increasing frequency and intensity of extreme weather events.

Bioremediation

Seaweeds efficiently absorb nutrients and heavy metals from the surrounding waters, making cultivating and restoring seaweed a promising bioremediation technique.[46] In China, seaweed farms have been critical in absorbing and cycling excess nutrient runoff that causes eutrophication of coastal waters – stifling marine ecosystems.[47] Seaweed can also be integrated into existing aquaculture operations to reduce the nutrient loading of surrounding waters, thereby purifying them.[24,73] Additionally, seaweed biomass is effective at sequestering heavy dissolved metals in the water column, and offer strong potential for remediating contaminated coastal areas.[46]



STUDY 1: HOW MUCH KELP IS IN BRITISH COLUMBIA?

A recent study by Dr. Alejandra Mora-Soto, commissioned by Ocean Wise, used aerial survey data and high-resolution satellite imagery to create a broad estimate of the total area of canopy-forming kelp beds off the coast of British Columbia. The study revealed at least 134 km^2 of bull kelp and 56 km^2 of giant kelp dotting the coastline from the Straight of Georgia up to Prince Rupert. This is a conservative estimate, as many kelp beds along the coast were not mapped due to gaps in data and technological limitations. Additionally, much of the kelp biomass in British Columbia is found in low-lying, or understory kelp species that are difficult to map from aerial imagery. This survey not only illustrates the abundance of kelp on our coasts, but also allows us to estimate the total biomass[vii] and therefore the amount of carbon stored in these underwater forests. Using previous estimates of carbon storage ratios,[viii] our model estimates that British Columbia's coast holds a standing stock[ix] of at least 14,778 tonnes of carbon, which represents the approximate amount of carbon that would be released into the atmosphere if these underwater forests were lost.

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"Despite the global importance of kelp forests, information on the extent and carbon sequestration potential of kelp forests are still missing for many marine ecosystems,[48] mainly due to technical challenges in mapping kelp using remote sensors.[49] Having an informed estimation of area and storage carbon would help decision-makers encourage kelp conservation and reforestation.

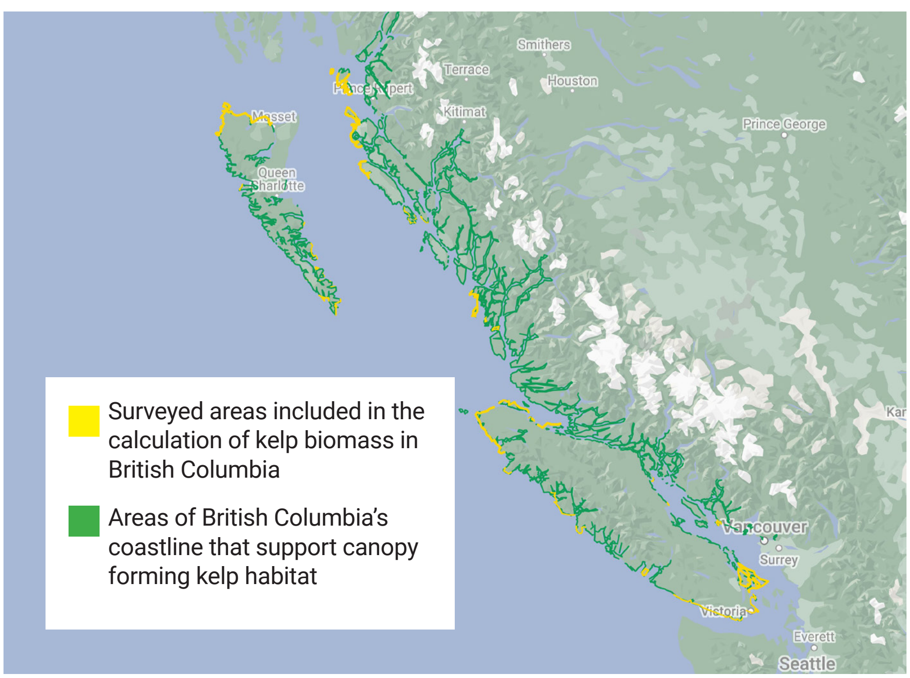
Forests of bull kelp and giant kelp are distributed along the British Columbia coastline and are under ongoing mapping efforts to assess their extent and dynamics.[50,51] Previous research has also estimated biomass and carbon and nitrogen storage ratios.[52,53,54] Using these data sources and validated carbon calculations,[55] we present a broad estimate of kelp area and carbon storage for BC. This methodology has many uncertainties and must be taken with caution; however, it is our best estimate for the moment."
– Dr. Alejandra Mora-Soto (2021)

vii Biomass - the mass of total organic material in an area or volume
viii Using conversion tables published by Filbee-Dexter & Wernberg (2020) but using the British Columbia wet-to-dry conversion rates for giant kelp and bull kelp (Wickham et al., 2019) and dry weight to Carbon percentage calculated for giant kelp (Wheeler & Druehl, 1986)
ix Standing stock - the amount of kelp present at the time of measurement

British Columbia	Total Area (km^2)	Wet Weight total (t)	Dry Weight total (t)	C (t)	Total NPP[x] (tC/yr-1)	Total CO_2 naturally Sequestered[xi] (tCO_2/yr-1)
Bull kelp	134	265,865	34,292	8,916	11,591	4,679
Giant kelp	56	196,055	22,546	5,862	7,620	3,076
Total	190	461,920	56,838	14,778	19,211	7,755

Using this estimate of carbon held in the standing stock, we can roughly calculate that the natural kelp forests in British Columbia sequester an annual amount of 7,755 metric tons of CO_2 every year – the equivalent emissions of heating 3,900 homes in B.C. using natural gas. However, we believe that carbon sequestered by B.C.'s kelp is significantly greater than this estimate for three reasons:

- There are many missing areas in this study, resulting in more kelp forests than are reported, in addition to the many understory kelp species that weren't mapped.
- Kelp continually shed tissue during their growth cycle, loosing biomass during storms and often replacing their entire canopy throughout the year.[34] Total Net Primary Production (NPP) can be extrapolated from the biomass held in the standing stock using a multiplier of 1.3, which was used in our estimate. However, this number may be range from 1.0 up to 5.0[56] which would result in much more sequestered carbon.
- The proximity of kelp beds to depths of greater than 1,000 meters[57] and heavy winter storm cycles in British Columbia present the possibility that a larger portion of carbon from kelp forests are transported and sequestered in the deep sea. Further research is needed to quantify the carbon sequestration potential of B.C.'s naturally occurring kelp forests.



This map illustrates the abundance of kelp habitat in British Columbia – a coastline that supports some of the highest kelp biodiversity on the planet. Adapted from the Global map of giant kelp forests.

x NPP calculated using a formula from Hutto et al. (2021), which multiplies biomass by 1.3 to account for tissue lost during growth This is a conservative estimate, as this multiplier may be as great as 2 times the biomass.
xi Total CO_2 Naturally sequestered calculated from numbers by Krause-Jensen and Duarte (2016), which equates NPP * 0.11 *3.67

Why seaforestation in British Columbia?

The interest in seaweed has recently exploded in British Columbia, due to many factors that make this province amenable to the expansion of seaweed cultivation and kelp forest restoration.

1. The coastline of British Columbia includes numerous inlets and islands, supporting many thousands of kilometres of kelp habitat.[58]
2. This natural kelp habitat supports the world's richest kelp flora, with over 22 different species native to local waters.[59]
3. The exact spatial potential for seaforestation in British Columbia is yet to be determined; however, there is a growing base of people working to further the science and in-water application of a responsible seaweed expansion.
4. British Columbia has a rich stable of academics, environmentalists, industrialists, and other interested parties that are already contributing to the advance of seaforestation.
5. There is significant interest from many Indigenous communities to explore the restoration, protection, and cultivation of seaweeds up and down the coast.
6. A viable kelp farming community exists in the province that can provide a strong launching point for the significant scaling-up of carbon sequestration and maximization of other environmental benefits through cultivation activities. Ocean-positive farming is a concept resonating increasingly with the seaweed industry in the province.

SEAFORESTATION PATHWAYS

To summarize the leading sections of this report, seaweed has been undervalued in its contributions to both carbon sequestration and economic value in British Columbia. Seaweed can play an important role in Canada's Net Zero future, from sequestering carbon in the deep seas, to providing reduced methane livestock feed, to creating low-carbon products. Additionally, seaweed offers a wide range of environmental, economic, and social benefits beyond the scope of climate change mitigation. The Clean BC Roadmap states that "to support the scale-up of Negative Emissions Technologies (NETs) by 2030, British Columbia needs an enabling environment that supports innovation, incentivizes public-private involvement and is flexible enough to adapt to change."[60] For these reasons, Ocean Wise is pursuing and promoting seaforestation, which is defined as the restoration, planting, management, and care of underwater seaweed forests.

In British Columbia, seaforestation offers three pathways - protection, restoration, and cultivation - that present potential to capture and sequester carbon, while providing a multitude of co-benefits if properly managed.

"Seaweed is arguably one of the most scalable nature-based solutions, offering possibilities for both decarbonizing the economy and sequestering carbon from the surface of the ocean"
– UN Global Compact, 2021

Protection

Overview
Conserving and protecting large areas of British Columbia's kelp forests allow for the continued process of natural carbon sequestration and the realization of the integral ecological support that these forests provide to their surrounding waters. Since kelp is potentially affected by local, preventable stressors, the strategy of protecting standing kelp corresponds, at least conceptually, to equivalent efforts to avoiding deforestation in terrestrial settings. Avoided deforestation is a recognized strategy in the mix of nature-based climate solutions.[61] Recently, the conservation of kelp meadows has been included in the carbon offsetting strategies of the City of Fukuoka in Japan, where blue carbon credits were established and sold in 2020.[62]

Considerations

Protection strategies formulated between governments and Indigenous Peoples are essential to achieving the dual goals of conserving biodiversity and supporting Indigenous rights and cultures - upholding the provincial government's commitments to UNDRIP. [xii,63]

Restoration

Overview

Significant declines in kelp abundance have already caused large socioeconomic impacts such as the closure of abalone fisheries in California and Rock Lobster fisheries in Australia.[18] Kelp forests can be degraded by a variety of stressors, but the primary causes of decline are linked to human activities. These include warming oceans due to climate change, direct erosion of kelp habitats, and the overfishing or hunting of keystone species[xiii] leading to ecosystem imbalances.[64]

Significant declines in kelp abundance have already caused large socioeconomic impacts such as the closure of abalone fisheries in California and Rock Lobster fisheries in Australia. Kelp forests can be degraded by a variety of stressors, but the primary causes of decline are linked to human activities.

A well cited example is the significant decline of kelp forests surrounding Haida Gwaii due to the over-hunting of sea otters in the 18th and 19th centuries. The extinction of sea otters on British Columbia's coast resulted in a population explosion of sea urchins, causing a widespread decline in kelp, as urchins can quickly wipe out entire forests if left under-predated.[64] Another example is the bull kelp forests of Northern California, which have seen a 90 per cent decline due to a series of ocean warming events combined with the decimation of the sunflower star population from an outbreak of Sea Star Wasting Disease in 2013.[65,66]

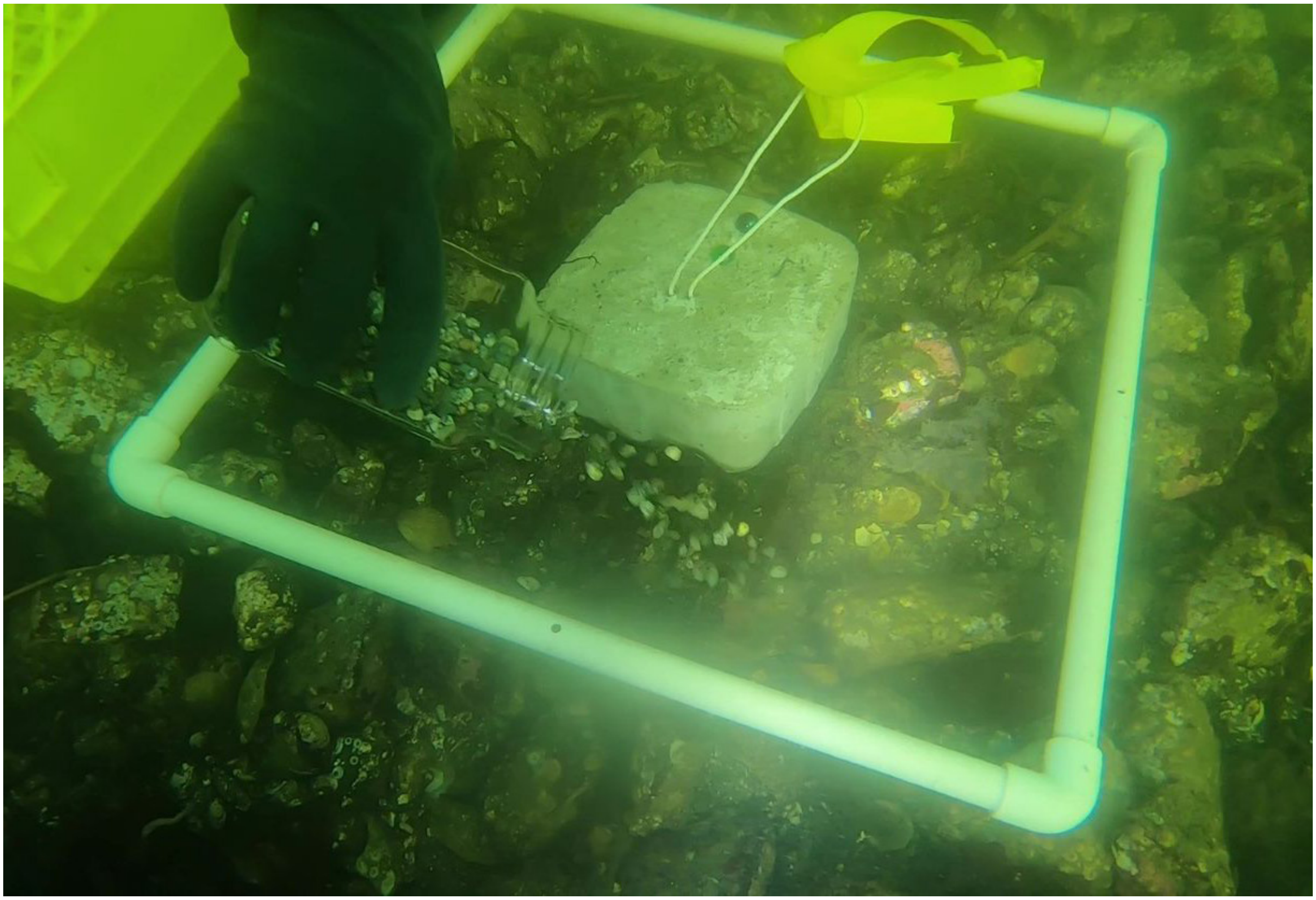
As the importance of kelp forests are better understood, there is a growing interest in restoration projects in degraded areas around the world. Efforts include the seeding or transplanting of kelp plants, the installation of artificial reef environments, as well as the removal of grazers such as sea urchins.[67]

Historically, restoration projects have been costly and labor intensive; however, Ocean Wise is working with local organizations to create cost-efficient, effective and scalable restoration methods such as Green Gravel – the seeding of juvenile kelp plants onto pebbles that can be distributed easily into degraded sites. Research and development into cost-effective and easily implemented restoration techniques offer methods that can be taken to scale across the world. This also presents the opportunity to transfer restoration methods into the hands of Indigenous communities and inform restoration interventions with traditional ways of knowing. Restoring kelp forests increases the capacity of communities to achieve food sovereignty.[xiv]

xii UNDRIP – the United Nations Declaration on the Rights of Indigenous Peoples. UNDRIP was partially adopted in Bill 49 – passed in B.C. in 2019.

xiii Keystone species – an organism that helps define an ecosystem and when removed significantly alters the foundations of the ecosystem.

xiv Food Sovereignty - the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods



The cost of restoring kelp forest varies significantly depending on the location, cause of decline, and method of restoration used. Currently, initial costs range from $13,100 to $57,600 per hectare for urchin removal.[67] Green gravel restoration currently costs between $38,000 to $93,800 per hectare,[68,69] but costs will decrease as methodologies are improved and economies of scale kick in. Combining restoration with cultivation is a possible method to help finance and incentivize restoration efforts and synergies between these two pathways should be explored. Furthermore, restored kelp forests can be sustainably wild harvested to produce additional economic potential.

Considerations

Site selection for successful kelp restoration projects in climate refugia[xv] must be carefully considered as warming oceans due to climate change pose a threat to the long-term viability of restored forests. Warming oceans present concerning pressures that have already directly and indirectly altered the structure and distribution of kelp forests around the world.[70] Preserving existing genetic diversity and selecting appropriate kelp species and genetic strains[xvi] is also integral to responsible seaforestation. Bull kelp forests are particularly affected by warming oceans, so isolating and planting heat-tolerant strains of bull kelp may be necessary to regenerate many important coastlines in the province. Restored kelp risks

xv Climate refugia - areas that remain relatively buffered from anthropogenic climate change over time
xvi Strain – a genetic variant or subtype within a defined species

genetic homogeneity – or the reduction of genetic diversity in a population – as well as the introduction of invasive species that could outcompete local kelp species.[71]

Conversely, warming oceans may create new habitat that could lead to the northern expansion of kelp forests in Canada.[70] This presents the option of speeding up the natural colonization process by introducing new kelp forests to quickly realize the many associated benefits that mature kelp creates; however, this requires a precautionary approach as the environmental impacts of the introduction of species into new environments must be first assessed.

Cultivation

Overview

Seaweed farming in British Columbia was initiated out of the Bamfield Marine Sciences Centre in the early 1980s.[72] Since its introduction, several small seaweed farms have operated in B.C., supported by two seaweed seed producers. However, currently in British Columbia seaweed is primarily wild harvested. Responsibly expanding seaweed farming can create green jobs throughout the supply chain and provide economic opportunities for coastal communities including Indigenous and remote communities.[73] Seaweed cultivation is substantially different from land-based agriculture or finfish aquaculture as seaweed absorbs all its nutrients from surrounding waters, meaning that farming seaweed requires zero fertilizer or water inputs.

Seaweed farming requires relatively low initial investment,[24] and it is estimated that it would cost between $25,000/ha[xvii] to $45,000/ha per year over the first 5 years to start a farm in British Columbia, including building infrastructure and obtaining an aquaculture tenure from the province.[74,75] One hectare of

xvii Initial costs averaged over a 5 year period cultivated ocean in the Northern Hemisphere can yield between 12 and 24 tons of wet seaweed per year depending on the species and management practices.[74,75] This generates between $9,600 - $120,000/ha in revenue depending on the quality of seaweed grown and level of processing added. This cultivated seaweed can be further purposed to generate low-carbon product alternatives — creating additional carbon sequestration above water. For example, biochar – an agricultural amendment that helps lock carbon in soil – can be synthesized from seaweed tissue, [77] or seaweed can be used as insulation material in construction, trapping CO_2 therein for decades.

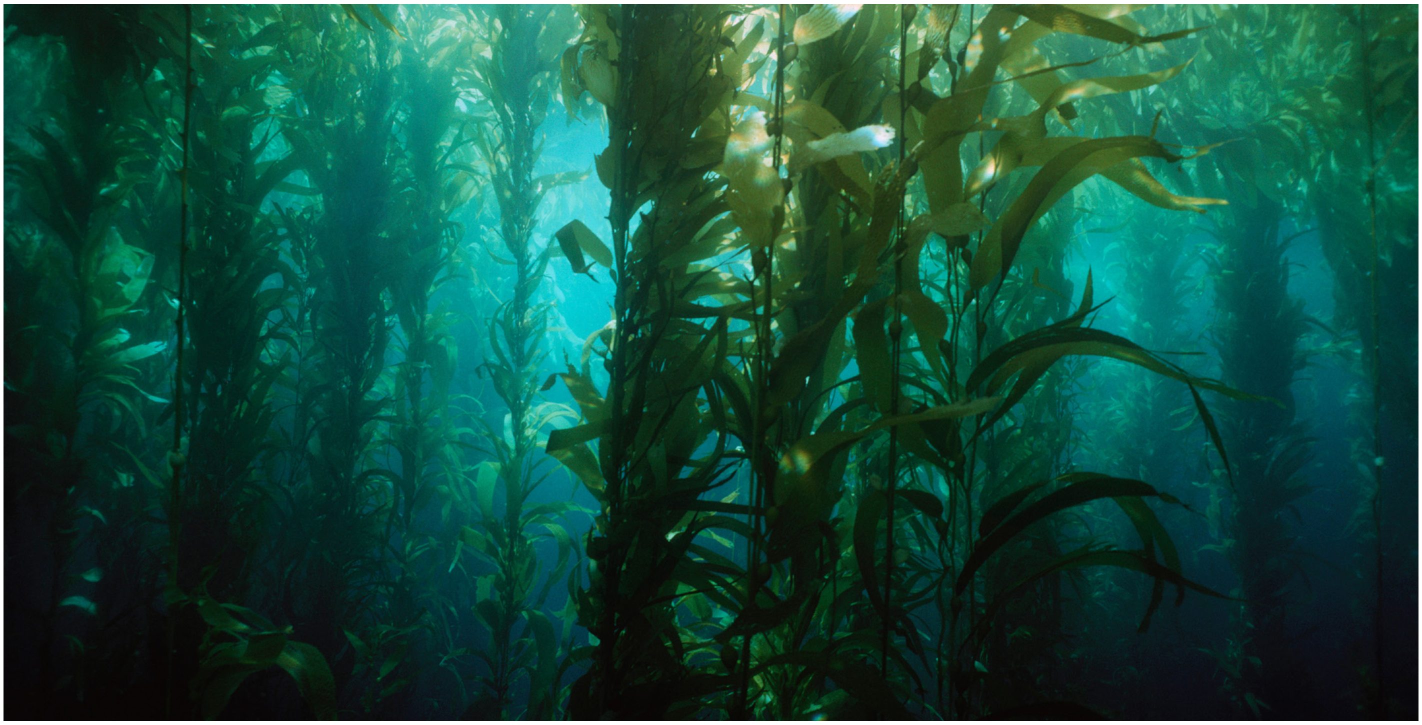
With proper management and regulation, seaweed cultivation can provide benefits to surrounding waters, absorbing excessnutrients, releasing oxygen, buffering against ocean acidification and creating temporary habitats for native species.

Natural carbon sequestration still takes place during cultivation as tissue breaks off from seaweed throughout the growing process. Research by Oceans 2050 in partnership with Prof. Carlos Duarte is exploring the carbon sequestration rates in sediments below seaweed farms across the globe. This research aims to allow seaweed farmers to monetize the carbon impact of their activities and provide market incentives.[78] Additionally, a percentage of cultivated seaweed could be set aside and sequestered using methods such as abyssal sinking – pending an evaluation of potential environmental impacts on the ocean floor.

This sequestration from cultivated seaweed produces opportunities in the carbon market. Canada's Minimum National Carbon Pollution Price Scale will allegedly raise the price per tonne of CO_2e $15 per year to reach a price of $170 per tonne in 2030.[79] While the 2030 price of carbon is not enough to incentivize seaweed farming solely for the purpose of sequestration, it provides economic incentives to farmers, while offering methods to partially fund the restoration of natural kelp forests.

Considerations

Aquaculture in British Columbia has been a point of contention and environmental concern, primarily due to the impacts of open-pen salmon farming. With the conversion of any ecosystem into a cultivated and controlled environment, there are risks that must be explored and mitigated when considering expanding seaweed cultivation in British Columbia. A thorough process of site selection is necessary to evaluate potential damage to sensitive marine environments, risk of interference and entanglement of marine mammals. A recent review conducted by Ocean Wise and Seaview Marine Sciences found that the risk of marine mammal entanglement is lower in seaweed farms than in other aquaculture facilities. However, the risk still exists and the need for an industry certification process is apparent to ensure safe practices.[80] Additional regulation is required to understand and mitigate the potential for disease impacts of non-native species, and other impacts on surrounding ecosystems – especially when examining large mono-cultured farming operations. It is also imperative to consider the social and economic impacts of expanding cultivation and working in partnership with local Indigenous groups to share management and economic benefit is essential in the implementation of any land use changes. With proper management and regulation, seaweed cultivation can provide benefits to surrounding waters, absorbing excess nutrients, releasing oxygen, buffering against ocean acidification and creating temporary habitats for native species.[81]



Abyssal sinking

Overview

The deliberate transport and sinking of cultivated seaweed biomass into the deep sea (depths greater than 1,000 meters) has the potential to sequester carbon for thousands of years, if not beyond human timescales. Seaweeds have been identified as the source of many oil deposits, suggesting they have been contributing to carbon sequestration for hundreds of millions of years.[8]

Abyssal sinking presents the opportunity to sequester large quantities of carbon in a method that is traceable and can therefore be verified by current carbon offset strategies. Various projects proposing abyssal sinking are already undergoing research and verification for their carbon sequestration potential. Additionally, abyssal sinking can be paired with cultivation to increase the carbon sequestered by seaweed farms while still providing the economic benefits of job creation, profits, low-carbon product alternatives and naturally occurring carbon sequestration.

Considerations

Abyssal sinking is in the early stage of research and development and there are still many unanswered questions, such as how much carbon would be sequestered under various oceanographic conditions, any adverse environmental impacts, and the economic feasibility of the process. Additionally, the costs and carbon footprint of collecting and transporting seaweed to the deep sea must be taken into account too. However, this method has the potential to outperform many land-based carbon sequestration solutions in the future and, therefore, deserves urgent scrutiny.[77]

HOW DOES SEAFORESTATION COMPARE TO REFORESTATION AND AFFORESTATION?

As nature-based climate solutions are more widely included in climate mitigation strategies, it is important to understand how they compare in cost, efficiency, and additional benefits beyond carbon sequestration alone.

Here we present rough values to compare the predicted costs of restoring and cultivating seaweed with the costs of Canada's 2 billion trees plan.

	Planting boreal forests	Restoring kelp forests	Cultivating seaweed (10% sunk)	Cultivating seaweed (40% sunk)
Tonnes CO_2 sequestered/ha (over 25 years)	73-220	44-75	40-105	90-240
Cost per tonne CO_2 sequestered[xviii] (over 25 years)	$10-33	$275-$1,050	$-7,200[xix]	$-5,862
Details	Canada plans to plant 2 billion trees over the next 10 years, with a total budget of 3.2 billion dollars.[82]	Restoring kelp forests through urchin removal or green gravel have high initial costs, but minimal to no annual costs after the forest has been reestablished. Costs will also decrease as the technology is improved.	Setting aside 10% of seaweed farm yield to be sunk into the abyss, results in profits for the farmer, while increasing the carbon sequestered each year.	Setting aside 40% of seaweed farm yield to be sunk into the abyss results in a break-even model, in which all costs are covered by the sale of the remaining 60%.
Additional benefits	• Benefits to human well-being (jobs, green spaces, reduced fire and flooding risk) • Biodiversity and resilience to climate change • Job creation	• Benefits to the ocean (biodiversity, wave attenuation, buffering ocean acidification) • Value to fisheries • Job creation • Food sovereignty for coastal Indigenous peoples	• Significant job creation • Nutrient removal • Benefits to the ocean • Decarbonization of the economy through innovative products	• Significant job creation • Nutrient removal • Benefits to the ocean • Decarbonization of the economy through innovative products
Value of Ecosystem Services	$6,000 - $48,000[83]	$175,000 - $237,000[18]		

xviii Cost per tonne CO_2 sequestered values do not include compensation from the sale of carbon credits.
xix Negative price per tonne CO_2 sequestered in the 10% sunk scenario refers to the profit made from the sale of the remaining crop.

Currently, planting trees still presents the lowest cost per tonne of CO_2 sequestered over a 25-year timespan. This low price is partially due to the scale of the project, maturity of the methods, and ease of working in terrestrial environments. Comparatively, kelp forest restoration is much more costly per tonne CO_2 sequestered in the initial 25 years of growth. However, kelp forests continue to sequester carbon year-on year, meaning the amount of carbon does not plateau and decline as is the case in terrestrial forests. As previously mentioned, a large portion of this carbon remains immune to external pressures, sequestered in the deep sea. Once our scientific understanding of the amount and permenance of carbon storage from natural and cultivated kelp beds improves, it is possible that the cost per tonne of CO_2 could become competitive with planting trees, especially when calculated over longer timescales.

Kelp forests continue to sequester carbon year-on year, meaning the amount of carbon does not plateau and decline as is the case in terrestrial forests.

Additionally, current restoration methods are still in the research and development phase, meaning costs will be significantly lowered with investment, streamlined processes, and economies of scale. Kelp forest restoration also brings significant co-benefits that are valued much higher than terrestrial forests. An estimate by Nature Conservancy of Canada and TD placed an annual ecosystem services value of between \$6,050 -\$48,100[xx] per hectare of Canadian forests.[83] Comparatively, an estimate by Eger et al. (pre-print 2021) projects the annual ecosystem services – including CO_2 drawdown and nutrient removal – by kelp forests in North America at \$175,000 – \$237,000 per hectare.[18]

Both kelp forest restoration and afforestation/reforestation efforts require initial investments and make no direct profits but are worthwhile endeavors from the point of view of bringing back kelp, building resilience and securing a path for long-term benefits from associated ecosystem services. Sequestering carbon through seaweed cultivation, on the other hand, offers a cost-effective, attractive solution that can create thousands of jobs and benefit surrounding waters. Here we present two cultivation scenarios, both which set aside a portion of the seaweed grown for carbon sequestration. The first scenario projects the "break-even" scenario, in which kelp farmers set aside approximately 40% of their yield to be sequestered, selling the remaining portion to cover the initial and annual costs associated with farming. While this leads to CO_2 sequestration per hectare that is comparable to forests with no costs, it is not likely the most attractive model to seaweed farmers. Alternatively, the second scenario projects farmers setting aside only 10% of their yield for carbon sequestration. This model is attractive, as farmers still make significant profit per hectare of seaweed, while sequestering carbon and benefiting from recognition through labelling and compensation depending on future carbon prices. There are still many knowledge gaps to fill in scenarios that include abyssal sinking; however, the benefits and low-risk nature of seaforestation offer a no-regrets opportunity for both British Columbia and Canada to seize with the power to shape a resilient, flourishing coastline that sequesters thousands of tonnes of CO_2 per year and provides a multitude of benefits to people, the climate, and the health of the oceans.

xx Adjusted to CAD 2020.

CONCLUSION

The effects of climate change are already impacting the ecosystems and people of British Columbia - necessitating the immediate deployment of multiple mitigation, carbon removal and adaptation strategies. Seaforestation presents a powerful solution that can improve the resilience of coastal food systems and ecosystems, and drawdown and sequester carbon through a variety of pathways.

Realistically, seaforestation can only play a small but necessary part in the grand scale of anthropogenic climate change mitigation. However, the many additional environmental and social benefits that accompany kelp forests create a no-regrets opportunity that must be maximized upon quickly. Aside from sequestering carbon, the protection and restoration of natural kelp forests is essential to supporting the astounding biodiversity of British Columbia's waters, sheltering animals from ocean acidification, and providing culturally important foods for coastal Indigenous Peoples. The cultivation of seaweed can have substantial benefits to surrounding waters, while also creating jobs that will help feed British Columbians and decarbonize our future economy. There are still knowledge gaps that must be addressed through research and regulatory frameworks that need to be adjusted to facilitate seaforestation; however, given the urgency of the climate crisis, it is essential to avoid paralysis and overcome those obstacles while concurrently expanding seaforestation in the province as a way of learning by doing. There are many steps that can be taken by all levels of government to encourage the realization of the considerable benefits of seaforestation.

ACTIONS AND POLICY RECOMMENDATIONS

INDIVIDUAL AND ORGANIZATION ACTIONS

- **Create a seed bank to preserve the genetic diversity of British Columbia's kelp**
- **Identify kelp strains with stress resistant properties and asses their potential to restore areas decimated by marine heat waves**
- **Socialize opportunities with Rightsholders and Stakeholders**
  a. Create space for extreme collaboration between private industry, non-profits, Indigenous Peoples, other communities, and governments.
  b. Consult with Indigenous and coastal communities to fit seaforestation into the socioeconomic

GOVERNMENT ACTIONS AND POLICY

- **Create a regulatory framework to help responsibly expand seaforestation in B.C. and monitor the impacts and efficacy of seaweed projects**
  a. Streamline the current aquaculture tenure process for seaweed farming
  b. Create a regulatory framework to mitigate environmental risks and monitor benefits
  c. Create a regulatory framework and adopt a "best-practices" guide for kelp forest restoration
  d. Create an eventual regulatory framework for abyssal sinking

- **Prioritize and fund ocean and climate literacy programs that raise awareness about nature-based climate solutions.**

- **Invest in the research and development of seaforestation techniques to responsibly take them to scale and maximize environmental, economic and social returns.**
  a. Determine ocean-positive cultivation practices that maximize carbon capture, sequestration, and ecological benefits
  b. Develop restoration techniques that are cost-effective, scalable, and work to provide economic and other social benefits to coastal communities
  c. Fund the development of seaweed-based products that are low-carbon or carbon-negative

- **Invest in a site-selection protocol for seaforestation interventions that is climate-proof and maximizes environmental, economic, and social returns.**

- **Implement better mapping, monitoring, and protection of existing seaweed forests**
  a. Protect large swaths of kelp forests under MPA's.
  b. Increase funding to mapping and monitoring projects
  c. Consolidate mapping and monitoring data between existing projects

- **Create financial incentives and investments, as well as regulatory adjustments for the responsible expansion of seaweed**
  a. Create funding opportunities for new seaweed farmers and communities that reduce barriers to seaweed cultivation
  b. Include kelp restoration projects in federal funding streams for nature-based climate solutions such as the Nature Smart Climate Solutions Fund
  c. Support the development of trading schemes for kelp-based carbon offsets and of protocols to develop and verify blue carbon credits for kelp.

- **Recognize seaweed's climate services within the projected national carbon balance, by accounting for carbon drawdown in restored and cultivated seaweed.**

URGENT APPLIED RESEARCH QUESTIONS

1. What is the potential in British Columbia to add restored and cultivated seaweed?
2. How much carbon is sequestered from British Columbia's natural kelp forests, and how can this be verified?
3. How much carbon can be sequestered through abyssal sinking, and what are impacts on deep ocean environments?
4. Which are the species and genetic strains of kelp most likely to withstand the impacts of climate change?
5. What management practices of cultivated and restored kelp forests can help maximize carbon sequestration and other environmental benefits?
6. How can strategic and climate-proof site choice and enhanced methods in farming and harvesting practices result in maximized carbon sequestration and other benefits?
7. What methods and technologies deliver the most cost-effective way to take restoration and cultivation to significant scale?
8. How does the responsible expansion of seaweed coincide with the interests, needs and opportunities of coastal Indigenous communities?
9. What are the environmental and operational safety boundaries of kelp restoration and seaweed farming at scale in British Columbia?

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