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EXPLORING THE ROLE OF SEAWEED CULTURE IN THE REDUCTION OF GREENHOUSE GAS EMISSIONS IN THE ATMOSPHERE: A NATURE-BASED SOLUTION FOR CLIMATE CHANGE MITIGATION

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ABSTRACT. To keep the world safe from extreme temperature occurrences, global warming must be kept below 1.5°C. Seaweed has emerged as a holistic nature-based solution to solve global warming by reducing greenhouse gases (GHGs). This review evaluated the role of seaweed in reducing GHGs. Seaweed can minimise carbon (C) emissions by absorbing them. Lowering ruminant enteric methane (CH_4) emissions and producing bioenergy are two more ways seaweed can contribute to global decarbonisation. Atmospheric trace gases like nitrous oxide (N_2O) are a factor in global warming. By 2050, 10 million metric tons (MMt) of nitrogen (N) would be absorbed by

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a seaweed yield of 500 MMt. All macroalgae release the volatile gas bromoform, which contributes to ozone (O_3) depletion in the atmosphere. Bromoform is a component of red seaweed's chemical composition. Large-scale seaweed cultivation can transform the way GHG emissions are managed while also generating new businesses. Furthermore, eutrophic, hypoxic, and acidic coasts can gain other advantages from seaweed cultivation. Although seaweed offsetting is a vital emerging tool for achieving a more sustainable future, it is not the only answer to the problem of climate change. This study demonstrates that seaweed cultivation and related sectors are viable solutions for lowering GHG emissions, achieving monetary growth, and creating sustainable means of subsistence.

Keywords: culture; global warming; greenhouse gases; minimization; seaweed.

INTRODUCTION

Approximately 71% of the Earth's surface is covered by water, which is crucial in regulating the Earth's climate. The oceans absorb a significant amount of carbon dioxide (CO_2) and heat from the atmosphere, helping mitigate greenhouse gas (GHG) effects on the climate (Bhuyan *et al.,* 2024a, 2025; Grorud-Colvert and Ward, 2023). Global warming is an ecological factor that continues to receive much attention from specialists. A rise in the amount of GHGs in the atmosphere, which traps more heat and warms the world, is the primary contributor to global warming (Mashoreng, 2019). The 2015 Paris Agreement aims to limit the increase in the world mean temperature to below 2°C, which will necessitate a swift and significant decrease in GHG emissions. By mid-century or shortly after, emissions must be "net zero," according to the Intergovernmental Panel on Climate Change (Sun *et al.,* 2021). Such drastic cuts must be made in such a short amount of time, necessitating system modifications on a scale never before seen and requiring extensive adjustments in all areas of the economy. The rising worry is that the required adjustments will not be made in time, resulting in excessive GHG emissions that will eventually need to be eliminated from the environment (Sonwani and Saxena, 2022).

GHG reduction has generally concentrated on methods for absorbing CO_2 from the atmosphere and storing it or using it in some other manners (Packer, 2009). Direct air capture, tree plantations, and restoration, as well as bioenergy with carbon (C) capture and storage, have received a lot of attention (Burns and Corbett, 2020). The seas already absorb around ten gigatons of CO_2 from the environment every year. There are several ways to boost the seas' ability to absorb CO_2; one of them is by increasing the development of seaweed (Webb *et al.,* 2021). Other than economic perspectives, seaweed also has an effective role in climate change (Bhuyan *et al.,* 2024a; Farhaduzzaman *et al.,* 2023; Islam *et al.,* 2020). Using cultivated seaweed for goods that save a gigaton of CO_2-eq GHG emissions yearly might yield a profit of \$50/tCO_2-eq, while sinking cultivated seaweed to the deep sea to bury a gigaton of CO_2 costs as little as US\$480/tCO_2 (DeAngelo *et al.,* 2022).

According to Bhuyan (2023) and Beas-Luna *et al.* (2020), seaweed is essential to the ocean's capacity to absorb GHGs. Seaweed is now thought to be the most efficient natural technique to absorb

C emissions from the atmosphere, even if forests are still regarded as the finest natural barrier in the fight against climate change (Bhuyan *et al.,* 2023, 2024b). Additionally, seaweed draws CH_4, N_2O, and fluorinated chemicals from the atmosphere (Bhuyan *et al.,* 2022a; Gillman, 2022). Seaweed expands by up to two feet per day, does not need fertilisers, and grows considerably more quickly than trees (Bhuyan *et al.,* 2021). Trapping GHGs can be quite effective in halting climate change (Godin, 2020). Additionally, seaweed reduces the negative effects of global warming on the ocean's diversity and the sources of nourishment and income for hundreds of millions of coastal people by reducing acidity, deoxygenation, and other ocean effects (Woody, 2019; Yong *et al.,* 2022). Furthermore, seaweed has a great role in the blue economy (Bhuyan *et al.,* 2022b).

DISCUSSION

Seaweed culture's role in greenhouse gas reduction

The majority of the GHG emissions that cause global warming are caused by human activities (Hassan *et al.,* 2023). Worries about global warming have prompted calls to decrease the use of fossil fuels while also restoring and safeguarding existing natural C sinks (Dooley *et al.,* 2022). Land trees are the most prominent of these natural sinks, but attention has been increasingly drawn to the benefits and capacity of coastline canopy ecosystems to store GHGs (Gallagher *et al.,* 2022). These are the highly productive environments for seaweed, saltmarsh, mangroves, and seagrass, generally stated as a blue C environment (Macreadie *et al.,* 2021; Hori *et al.,* 2019). Seaweed has a significant role in lowering atmospheric GHG levels (Bhuyan, 2023; Bhuyan *et al.,* 2021, 2022a).

Carbon dioxide reduction

The amount of CO_2 in the atmosphere has increased globally over the past 150 years by 40%, reaching 407 ppm. By 2100, this level is predicted to rise to 1000 ppm, which will cause a pH drop of 0.3. By 2100, the sea surface temperature is expected to rise by 1.5-4°C (Minich *et al.,* 2018). To stop global warming and a future climatic disaster, it will be imperative to remove CO_2 from the atmosphere (Hurlimann, 2019). As deforestation destroys rainforests and other essential C sinks, the potential of seaweed culture is to combat climate change (Bhuyan *et al.,* 2021). Seaweed and other macrophytes are incredibly effective at storing C in their rapidly expanding oceanic environment. Just 0.001% of the world's seaweed-growing waters may be used to grow macroalgae, which could then be submerged at sea to reduce global C emissions (Bhuyan *et al.,* 2022a; Woody, 2019).

Growing seaweed, such as kelp and other algae, removes CO_2 from the ocean (Kaladharan *et al.,* 2009). Seaweeds are excellent at acquiring and storing C because they have a rapid growth rate and a long lifespan (Bhuyan *et al.,* 2024a). Trees are less effective in absorbing CO_2 than seaweed. Large amounts of CO_2 are absorbed by seaweed (Azeez, 2021). Approximately 50% of the C that is stored on the seafloor comes from seaweed. A substantial percentage of that C can linger in the ocean for probably hundreds of years. Seaweeds absorb extra

C, N, and other nutrients via photosynthesis to create new biomass and release oxygen (Bedolfe, 2017; Thomson, 2021). Thus, seaweeds act as C sinks and restore the marine ecosystem by reducing acidity and supplying habitat for aquatic life (Li, 2019).

Seaweed farming is the fastest-growing component of the global food supply and offers several opportunities to slow down and respond to climate change (Bhuyan *et al.,* 2022a; Duarte *et al.,* 2022). Consequently, seaweed ventures work as CO_2 sinks by releasing C that may be buried in sediment or exported to the deep ocean (Duarte *et al.,* 2017). Similar to land plants, as seaweed grows, it absorbs C from the atmosphere and deposits it as biomass.

However, unlike terrestrial forests, the C stored in seaweed is not at risk from fire and deterioration. Some types of seaweed have gas bladders in their fronds that enable them to drift close to the top where sunlight may reach them (Goldstein-Rose, 2021). The seaweed's bladders allow it to float for a long distance before bursting, which causes it to drop to the deep-ocean floor, where the C is trapped for thousands to millions of years (Bhuyan, 2023; Hurlimann, 2019).

According to Garca-Poza *et al.* (2020), seaweed spontaneously absorbs roughly 640 metric tons of CO_2 per year, with over 90% stored in deep water. Froehlich *et al.* (2019) reported that sunken seaweed can absorb 1,110 tons of CO_2/km^2 of seaweed cultivated areas. In case of reduced releases from fossil fuels, seaweed biofuels might prevent around 1,500 tons of CO_2/km^2 of seaweed cultivation area each year (Webb *et al.,* 2021). The 500 million metric tons (MMt) of seaweed produced would use 135 MMt of C, or 3.2% of the C released to seawater annually due to GHG emissions (Work, 2017). The assimilation of C ~1 PgC/y is accounted for by seaweeds and seagrasses. Mangroves, saltmarshes, and seagrasses are thought to be able to capture 70% of the C in the maritime environment (Sondak *et al.,* 2017). Seaweed aquaculture beds in the Asia-Pacific area have the potential to absorb over 694,636 t of C/year (Sondak *et al.,* 2017). The CO_2 sequestration by seaweed aquaculture beds in the Asia-Pacific area is shown in *Figure 1*.

Half of the C that is stored in the world's coastal seas comes from macro-vegetated marine environments (Bhuyan *et al.,* 2022a, 2024a). Highly photosynthetic seaweed populations worldwide take up 1.5 Pg C/year through net production, making the seaweed yield from wild stocks and farmed a major way to capture CO_2 from the environment (Duarte *et al.,* 2017; Mashoreng, 2019). Seaweed culture has a maximum annual CO_2 collection capacity of 2.48 MMt.

The maximum CO_2 capture capacity of seaweed cultivation would surpass 6% of the total CO_2 absorption by natural kelp by 2050 if present growth rates continue. About 961 kg CO_2/ton is removed from the atmosphere via seaweed aquaculture's biofuel generation (Duarte *et al.,* 2017). Seaweed communities thrive, and those dominated by *Laminaria hyperborea* can produce up to 3 kg/Cm^2 annually. Every year, seaweeds harvested for commercial purposes remove close to 0.7 MMt of C from the ocean (Chung *et al.,* 2013).

Figure 1 – Estimations of yearly possible CO_2 sequestration by seaweed aquaculture beds in the Asia-Pacific area (Data source: FAO FIGIS, 2016)

Beardall and Raven (2004) estimate that ocean photosynthesis provides 54–59 PgC/year of the planet's total primary production, with seaweeds and seagrasses contributing only ~1 PgC/year. Seaweeds also have a promising prospect for absorbing C since macroalgae may add 0.26×10^6 tons of C to the collected seaweed yearly (Chung *et al.,* 2011; Sahoo, 2012). The idea of a littoral CO_2 elimination belt was put forth by Chung *et al.* (2013), who also estimated that a project in Korea might sequester up to 10 tons of CO_2 equivalent per hectare each year. According to Krause-Jensen and Duarte (2016), seaweeds might sequester roughly 173 TgC each year worldwide. Transportation to the deep-sea accounts for about 90% of this absorption, with coastal sediments accounting for the remaining 10% (Chung *et al.,* 2017). A total of 8.23 tons of CO_2/ha/cycle is absorbed by marine algae. Takalar District in Indonesia provided the most C sequestration, contributing a calculated 771492.4 tons per year (Mashoreng, 2019). The possibility to sequester 1 of CO_2/year through the farming of seaweed in Indonesia is presented in *Figure 2*.

Methane (CH_4) reduction

Climate change is mostly caused by GHGs, and CH_4 is a powerful GHG (Kannadhasan and Nagarajan, 2023). As a potent GHG with about 80 times the heating potential of CO_2 in the initial 20 years after emission, CH_4 has a significant impact on upcoming heating and the temperature increase over the following few years (Oni *et al.,* 2023). It contributes to around 11% of the GHG emissions in the United States and has a global warming possibility 28 times greater than CO_2 on a 100-year timeline

(Roque *et al.,* 2019). By enhancing soil health and replacing synthetic fertilisers, seaweed farming can also aid in reducing emissions from agriculture. Whenever it is fed to cattle, seaweed also lowers the CH_4 emissions from livestock (Duarte *et al.,* 2017).

Adding a modest amount of *Asparagopsis taxiformis* to cow feed can reduce the emission of CH_4 from beef cattle by up to 99% (Godin, 2020; Li, 2019). Farmers can feed their animals with seaweed as feed. In its role as fertiliser, it promotes plants' nutrient absorption and aids in the fight against soil-related diseases. Using livestock feed can lessen the amount of CH_4 that cows generate.

Ruminant diets containing *A. taxiformis* and *Asparagopsis aramata* had significantly reduced levels of enteric CH_4. Li *et al.* (2018) reported a relationship between feeding sheep *A. taxiformis* and CH_4 generation and discovered an 80% decrease in CH_4 when compared to a control diet.

Similar findings were obtained by Roque *et al.* (2019) for cows given *A. taxiformis* and by Kinley *et al.* (2020) for Brahman–Angus cross steers, which had reductions in CH_4 of between 40% and 98%.

Various seaweed farming businesses are currently functioning in several nations to reduce CH_4 emissions. Many of these businesses concentrate on the growth of either *A. taxiformis* or *A. aramata* (Abbott *et al.,* 2020).

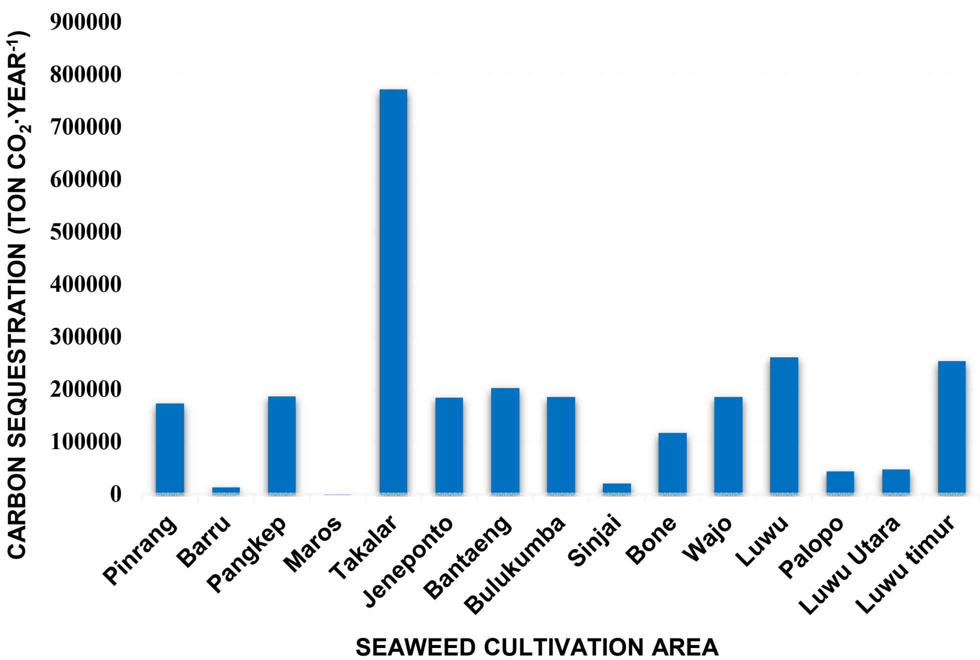

Figure 2 – Potential to sequester 1 ton of CO_2/year through the cultivation of seaweed in Indonesia (Data source: Mashoreng, 2019)

A. taxiformis has a bioactive bromoform that has been demonstrated to drastically lower animal intestinal CH_4 generation (Magnusson *et al.,* 2020; Vega *et al.,* 2023). In addition, some other seaweeds, such as *Alaria esculenta*, *Ascophyllum nodosum*, and *Chondrus crispus*, have been discovered to have the ability to lower CH_4 emissions from ruminants. The chemical bromoform, which is present in many seaweed species but mainly in *Asparagopsis* sp., is largely responsible for the CH_4 decrease. It is reported that bromoform blocks the methanogens' mechanism for producing CH_4 (Abbott *et al.,* 2020). Nevertheless, additional substances have been shown to have the capacity to restrict methanogens like Archaea and may be able to lower CH_4 emissions. These substances include lipids, carbohydrates, phlorotannins, and peptides (Min *et al.,* 2021).

There is proof that feeding large amounts of seaweed to cattle can lower the creation of CH_4; however, the outcomes are highly unpredictable (McGregor *et al.,* 2021; Wang *et al.,* 2022). Red seaweed may be able to cut CH_4 production by 95% when given in a diet at a rate of 5% organic matter addition, according to in vitro research. An in vivo investigation of dairy cows employing the similarly related species *A. armata* revealed that at a 1% level of dry matter incorporation in the diet, CH_4 generation and production reduced by 67% and 43%, respectively.

Feeding *A. taxiformis* (0.10% and 0.20%) of the dry matter in the diet for 90 days reduced the release of CH_4 in steers by up to 40% and 98% (Glasson *et al.,* 2022; Vijn *et al.,* 2020). *Table 1* depicts the contribution of different seaweeds to reducing CH_4 emissions from the atmosphere.

Nitrous oxide (N_2O) reduction

N_2O is one of the atmospheric trace gases that cause global warming. It has a chance of causing global warming around 310 times greater than CO_2 (Albert *et al.,* 2013). A total of 500 MMt of seaweed produced globally by 2050 would remove 10 MMt of N, or 30% of the N predicted to reach the ocean, and 15 MMt of phosphorus (P), or 33% of the total P produced by fertiliser (Chopin and Tacon, 2021; Jagtap and Meena, 2022; Work, 2017). Excess N from synthetic fertilisers often enters rivers and oceans, leading to algal blooms and increased N_2O emissions through microbial processes. Seaweed absorbs excess N from the water, preventing the conditions that lead to N_2O release (Kim, 2024). Farming near agricultural runoff areas can act as a biofilter, improving water quality and reducing N_2O formation. Some seaweed species, particularly *A. taxiformis*, have been shown to reduce CH_4 emissions from cows, but they also impact N metabolism (Roque *et al.,* 2021). This leads to less N excretion in manure, which in turn reduces N_2O emissions from manure decomposition. In fish and shrimp farms, excess feed and waste increase N levels, leading to higher N_2O emissions. Integrating seaweed into aquaculture (Integrated Multi-Trophic Aquaculture) helps absorb N, thereby reducing N_2O formation. Seaweed forests support microbial communities that play a role in denitrification, converting N compounds into harmless N_2 gas instead of N_2O (Perring *et al.*, 2025). This process interrupts the N cycle, lowering N_2O emissions from coastal and marine environments. By absorbing N, improving livestock digestion, and supporting beneficial microbial processes, seaweed can significantly reduce N_2O emissions, contributing to climate change mitigation. Expanding seaweed farming and integrating it into agriculture and aquaculture could be a powerful strategy for cutting global GHG emissions.

Table 1 – Roles of different seaweeds in CH_4 mitigation

Seaweed	Seaweed Types	Seaweed Dose (% of Dry Matter or Organic Matter Incubated)	CH_4 Decrease vs. Control	References
Alaria esculenta	Red	13, 23, 31	Linear↓ with increasing dose	Ramin *et al.*, 2018
Asparagopsis taxiformis	Red	5	No effect at 24 h, ↓ 74% at 48h	Brooke *et al.*, 2018
		1, 2	↓>99%	Chagas *et al.*, 2019
		0.006, 0.013, 0.025, 0.05, and 0.1	↓100 for ≥0.05	Chagas *et al.*, 2019
		0.5, 1, 2, 5, 10	↓100% for≥1%	Kinley *et al.*, 2016
		2%	↓100%	Kinley *et al.*, 2016
		16.6	↓100%	Machado *et al.*, 2014
		0.07, 0.125, 0.25, 0.5, 1, 2, 5, 10, and 16.8	No effect for _0.5%, ↓85% for 1%, ↓100% for ≥%	Machado *et al.*, 2016a, 2016b
		2	↓100%	Machado *et al.*, 2018
Chondrus crispus	Red	0.5	↓12%	Kinley and Fredeen, 2015
Furcellaria sp.	Red	0.5	↓10%	Kinley and Fredeen, 2015
Gigartina sp.	Red	25	↓56%	Maia *et al.*, 2016
Gracilaria sp.	Red	2, 4, 5, 7	↓49% for 2%, small ↓ for ≥4%	Prayitno *et al.*, 2018
Hypnea pannosa	Red	16.6	↓43%	Machado *et al.*, 2014
Laurencia filiformis	Red	16.6	↓40%	Machado *et al.*, 2014
Gracilaria vermiculophylla	Red	25	↓41%	Maia *et al.*, 2016
		25	↓37%	Maia *et al.*, 2016
Ascophyllum nodosum	Brown	11.1	15% at 24 h	Wang *et al.*, 2008
Padina australis	Brown	16.6	↓51%	Machado *et al.*, 2014

Sargassum flavicans	Brown	16.6	↓34%	Machado *et al.*, 2014
Dictyota bartayresii	Brown	16.6	↓92%	Machado *et al.*, 2014
Cladophora patentiramea	Green	16.6	↓66%	Machado *et al.*, 2014
Colpomenia sinuosa	Brown	16.6	↓49%	Machado *et al.*, 2014
Cystoseira trinodis	Brown	2, 3.8, 7.4, 13.8	↓73% for ≥3.8% only	Dubois *et al.*, 2013
		16.6	↓45%	Machado *et al.*, 2014
Hormophysa triquetra	Brown	16.6	↓44%	Machado *et al.*, 2014
Zonaria farlowii	Brown	5	↓11% at 24 h only	Brooke *et al.*, 2018
Caulerpa taxifolia	Green	16.6	↓33%	Machado *et al.*, 2014
Chaetomorpha linum	Green	16.6	↓40%	Machado *et al.*, 2014
Ulva ohnoi	Green	16.6	↓45%	Machado *et al.*, 2014
Ulva sp.	Green	16.6	↓50%	Machado *et al.*, 2014
		25	↓45%	Maia *et al.*, 2016

Note: ↓= Decrease; > =Greater than; ≥ = Greater than or equal; h= Hour; % = Percentage

Fluorinated gases: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HFC)s, and halons reduction

Seaweed does not directly absorb or break down fluorinated gases such as HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF□), which are synthetic GHGs used in refrigeration, electronics, and industrial processes (Al-Adilah *et al.,* 2022). However, seaweed can indirectly contribute to reducing F-gas emissions. Considering their extreme and potent influence on the climate, HFC, PFCs, SF_6, and NF_3 have been referred to as "super contaminants" and "super GHGs." They are the most potent GHGs now understood by science, some of which have up to 24,000 times the possibility of causing global warming as CO_2 (Sovacool *et al.,* 2021). It is still not known how seaweed reduces fluorinated emissions. More research is required on this. While seaweed does not directly absorb or degrade F-gases, it plays a role in reducing their sources by offering eco-friendly alternatives in cooling, packaging, and industry (Osorio, 2019). Promoting seaweed-based solutions can help minimise reliance on F-gas-intensive processes, contributing to overall GHG reduction.

Ozone (O_3) reduction

Most seaweeds produce the volatile gas bromoform, which is assumed to be the main component in seaweed that causes this impact and contributes to the O_3 hole in the atmosphere (SJSU, 2022). Red seaweed contains a chemical called bromoform. It is well known that this chemical destroys O_3; hence, further manufacturing of it is probably controversial. While seaweed grows, a chemical is released (Fonterra, 2018). This would make it impossible for red seaweed to be cultivated commercially or at least present significant obstacles. The predicted growth of the seaweed sector, especially if it concentrates on some of the seaweeds that produce the most bromoform, could have a substantial effect on the stock of O_3 in the atmosphere as well as the natural sea-to-air transit of brominated chemicals (SJSU, 2022).

CONCLUSIONS

Seaweed plays a significant role in reducing GHGs through various mechanisms. By expanding seaweed cultivation and utilisation, we can significantly contribute to global climate change mitigation. To support more than 9 billion people in 2050, seaweed farming must be scaled up as an emissions absorption and utilisation technology that supports a circular bioeconomy. Global concern has arisen due to the substantial rise in GHG emissions since industrialisation. Seaweeds play a significant role in coastal habitats ranging from kelp beds to corals. They are rivals, important primary producers from an ecological standpoint, and ecosystem designers. Seaweed also provides a flexible, natural approach to coping with and adapting to climate change. According to the findings of the present study, seaweed is a sustainable, nature-based solution for eliminating GHGs from the atmosphere and making the world liveable for humans.

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REFERENCES

Abbott, D.W.; Aasen, I.M.; Beauchemin, K.A.; Grondahl, F.; Gruninger, R.; Hayes, M.; Xing, X. Seaweed and seaweed bioactives for mitigation of enteric methane: Challenges and opportunities. *Animals* **2020**, *10* (12), 2432. https://doi.org/10.3390/ani10122432

Albert, K.R.; Bruhn, A.; Ambus, P. Nitrous oxide emission from *Ulva lactuca* incubated in batch cultures is stimulated by nitrite, nitrate and light. *Journal of Experimental Marine Biology and Ecology* **2013**, *448*, 37-45. https://doi.org/10.1016/j.jembe.2013.06.010

Al-Adilah, H.; Feiters, M.C.; Carpenter, L.J.; Kumari, P.; Carrano, C.J.; Al-Bader, D.; Küpper, F.C. Halogens in seaweeds: biological and environmental significance. *Phycology* **2022**, *2* (1), 132-171. https://doi.org/10.3390/phycology2010009

Azeez, W. These 4 start-ups are using seaweed to help save the planet. World Economic Forum. https://www.weforum.org/agenda/2021/05/startups-seaweed-farming-ocean-planet-climate/ (accesed on 25May 2021).

Beardall, J.; Raven, J.A. The potential effects of global climate change on microalgal photosynthesis, growth and ecology. *Phycologia* **2004**, *43* (1), 26-40. http://dx.doi.org/10.2216/i0031-8884-43-1-26.1

Beas-Luna, R.; Micheli, F.; Woodson, C.B.; Carr, M.; Malone, D.; Torre, J.; Torres-Moye, G. Geographic variation in responses of kelp forest communities of the California Current to recent climatic changes. *Global Change Biology* **2020**, *26* (11), 6457-6473. https://doi.org/10.1111/gcb.15273

Bedolfe, S. Seaweed could be scrubbing way more carbon from the atmosphere than we expected. Oceana. Retrieved from https://oceana.org/blog/seaweed-could-be-scrubbing-more-carbon-atmosphere-we-expected/#:~:text=By%20dying%20and%20drifting%20down,it%20comes%20to%20storing%20carbon (accesed on 6 October 2017).

Bhuyan, M.S.; Senapathi, V.; Karthikeyan, S.; Kunda, M.; Islam, M.T.; Iheanacho, S.; Choudhury, A.K. Microplastics contamination in seaweed: impacts on human health and mitigation approaches. *Discover Oceans* **2025**, *2* (1), 2. https://doi.org/10.1007/s44289-025-00041-0

Bhuyan, M.S.; Haider, S.M.B.; Kunda, M.; Islam, M.T.; Husain, S.A.; Chowdhury, E.; Mojumder, I.A. Is seaweed culture a sustainable approach to climate change adaptation? *Journal of NOAMI* **2024a**, *38* (1-2), 75-88.

Bhuyan, M.S.; Kunda, M.; Bakar, M.A.; Senapathi, V.; Husain, S.A.; Chowdhury, E.; Pandit, D. Heavy metal and mineral analysis of cultivated seaweeds from Cox's Bazar Coast, Bay of Bengal, Bangladesh: a human health risk implication. *Discover Oceans* **2024b**, *1* (1), 11. https://doi.org/10.1007/s44289-024-00012-x

Bhuyan, M.S.; Haider, S.M.B.; Kundu, M.; Husain, S.K.A.; Chowdhury, E. Challenges in Cultivation of Seaweed: A Recent Experience from RezuKhal, Cox's Bazar Coast, Bangladesh. *Journal of Oceanography & Marine Environmental System* **2023**, *7*, 01-09. http://dx.doi.org/10.5829/idosi.jomes.2023.01.09

Bhuyan, M.S. Ecological risks associated with seaweed cultivation and identifying risk minimization approaches. *Algal Research* **2023**, 102967. https://doi.org/10.1016/j.algal.2022.102967

Bhuyan, M.; Abid Husain, S.; Chowdhury, E.; Bat, L. Assessment of carbon sequestration capacity of seaweed in climate change mitigation. *Journal of Climate Change* **2022a**, *8* (1), 1-8. http://dx.doi.org/10.3233/JCC220001

Bhuyan, M.S.; Islam, M.N.; Ali, M.M.; Rashed-Un-Nabi, M.; Alam, M.W.; Das, M.; Mustary, S. Blue economy prospects, opportunities, challenges, risks, and sustainable development pathways in Bangladesh. *Global Blue Economy* **2022b**, 147-194. http://dx.doi.org/10.1201/9781003184287-6

Bhuyan, M.; Islam, M.; Sharif, A.S.M.; Hoq, M. Seaweed: A powerful tool for climate change mitigation that provides various ecological services. *Bangladesh II: Climate Change Impacts, Mitigation* *and Adaptation in Developing Countries* **2021**, 159-192. http://dx.doi.org/10.1007/978-3-030-71950-0_5

Brooke, C.G.; Roque, B.M.; Najafi, N.; Gonzalez, M.; Pfefferlen, A.; DeAnda, V.; Hess, M. Evaluation of the potential of two common Pacific coast macroalgae for mitigating methane emissions from ruminants. *bioRxiv* **2018**, 434480. https://doi.org/10.1101/434480

Burns, W.; Corbett, C.R. Antacids for the sea? Artificial ocean alkalinization and climate change. *One Earth* **2020**, *3* (2), 154-156. https://doi.org/10.1016/j.oneear.2020.07.016

Chagas, J.C.; Ramin, M.; Krizsan, S.J. In vitro evaluation of different dietary methane mitigation strategies. *Animals* **2019**, *9* (12), 1120. https://doi.org/10.3390/ani9121120

Chopin, T.; Tacon, A.G. Importance of seaweeds and extractive species in global aquaculture production. *Reviews in Fisheries Science & Aquaculture* **2021**, *29* (2), 139-148. https://doi.org/10.1080/23308249.2020.1810626

Chung, I.K.; Oak, J.H.; Lee, J.A.; Shin, J.A.; Kim, J.G.; Park, K.S. Installing kelp forests/seaweed beds for mitigation and adaptation against global warming: Korean Project Overview. *ICES Journal of Marine Science* **2013**, *70* (5), 1038-1044. https://doi.org/10.1093/icesjms/fss206

Chung, I.K.; Sondak, C.F.; Beardall, J. The future of seaweed aquaculture in a rapidly changing world. *European Journal of Phycology* **2017**, 52 (4), 495-505. http://dx.doi.org/10.1080/09670262.2017.1359678

Chung, Y.H.; Walker, N.D.; McGinn, S.M.; Beauchemin, K.A. Differing effects of 2 active dried yeast (*Saccharomyces cerevisiae*) strains on ruminal acidosis and methane production in nonlactating dairy cows. *Journal of Dairy Science* **2011**, *94*(5), 2431-2439. https://doi.org/10.3168/jds.2010-3277

DeAngelo, J.; Saenz, B.T.; Arzeno-Soltero, I.B.; Frieder, C.A.; Long, M.C.; Hamman, J.; Davis, S.J. Economic and biophysical limits to seaweed farming for climate change mitigation. *Nature Plants* **2023**, *9*, 45-57. https://doi.org/10.1038/s41477-022-01305-9

Dooley, K.; Nicholls, Z.; Meinshausen, M. Carbon removals from nature restoration are no substitute for steep emission reductions. *One Earth* **2022**, *5* (7), 812-824. https://doi.org/10.1016/j.oneear.2022.06.002

Duarte, C.M.; Bruhn, A.; Krause-Jensen, D. A seaweed aquaculture imperative to meet global sustainability targets. *Nature Sustainability* **2022**, *5* (3), 185-193. https://doi.org/10.1038/s41893-021-00773-9

Duarte, C.M.; Wu, J.; Xiao, X.; Bruhn, A.; Krause-Jensen, D. Can seaweed farming play a role in climate change mitigation and adaptation? *Frontiers in Marine Science* **2017**, *4*, 100. https://doi.org/10.3389/fmars.2017.00100

Dubois, B.; Tomkins, N.W.; Kinley, R.D.; Bai, M.; Seymour, S.; Paul, N.A.; de Nys, R. Effect of tropical algae as additives on rumen in vitro gas production and fermentation characteristics. *American Journal of Plant Sciences* **2013**, *4*, 34-43. http://dx.doi.org/10.4236/ajps.2013.412A2005

Farhaduzzaman, A.M.; Khan, M.S.; Hasan, M.; Islam, R.; Osman, M.H.; Shovon, M.N.H.; Haider, S.M.B.; Kunda, M.; Islam, M.T.; Bhuyan, M.S. Seaweed Culture, Post-Harvest

Processing, and Market Generation for Employment of Coastal Poor Communities in Cox's Bazar. *Journal of Applied Life Sciences and Environment* **2023**, *56, 231-244.* https://doi.org/10.46909/alse-562098

Fonterra. Seaweed resurfaces. Available online: https://www.fonterra.com/nz/en/our-stories/articles/seaweed-resurfaces.html (accessed on 2 July 2018).

Froehlich, H.E.; Afflerbach, J.C.; Frazier, M.; Halpern, B.S. Blue growth potential to mitigate climate change through seaweed offsetting. *Current Biology* **2019**, *29* (18), 3087-3093. https://doi.org/10.1016/j.cub.2019.07.041

Gallagher, J.B.; Shelamoff, V.; Layton, C. Seaweed ecosystems may not mitigate CO_2 emissions. *ICES Journal of Marine Science* **2022**, *79* (3), 585-592. https://doi.org/10.1093/icesjms/fsac011

García-Poza, S.; Leandro, A.; Cotas, C.; Cotas, J.; Marques, J.C.; Pereira, L.; Gonçalves, A.M. The evolution road of seaweed aquaculture: cultivation technologies and the industry 4.0. *International Journal of Environmental Research and Public Health* **2020**, *17* (18), 6528. http://dx.doi.org/10.3390/ijerph17186528

Gillman, R. Challenges and prospects: Reducing US methane emissions via red macroalgae (*Asparagopsis taxiformis*) feed additives to inhibit enteric methane production from ruminant livestock. PhD thesis, Yale University, New Haven, United States, January 2022. https://elischolar.library.yale.edu/cgi/viewcontent.cgi?article=2148&context=ysphtdl

Glasson, C.R.; Kinley, R.D.; de Nys, R.; King, N.; Adams, S.L.; Packer, M.A.; Magnusson, M. Benefits and risks of including the bromoform containing seaweed *Asparagopsis* in feed for the reduction of methane production from ruminants. *Algal Research* **2022**, *64* (4), 102673. http://dx.doi.org/10.1016/j.algal.2022.102673

Godin, M. The ocean farmers trying to save the world with seaweed. Time. Available online: https://time.com/5848994/seaweed-climate-change-solution (accessed on 19 August 2020).

Goldstein-Rose, S. From fake meat to cow burps: 5 ways to use seaweed to tackle climate change. IDEAS.TED.COM. Available online: https://ideas.ted.com/seaweed-can-help-reduce-carbon-emissions-and-address-climate-change/ (accessed on 17 September 2021).

Grorud-Colvert, K.; Ward, M. The Ocean an Introduction to the Marine Environment. Oceans and Society: An Introduction to Marine Studies. Available online: https://ideas.ted.com/seaweed-can-help-reduce-carbon-emissions-and-address-climate-change/ (accessed on 2023).

Hassan, M.U.; Batool, M.; Farooq, T.H.; Arif, M.S.; Aamer, M.; Waqas, M.A.; Shakoor, A. How does dolomite application affect the greenhouse gases emissions from the terrestrial environment? -A global synthesis. *Fuel* **2023**, *332*, 126048.

Hori, M.; Bayne, C.J.; Kuwae, T. Blue carbon: characteristics of the Ocean's sequestration and storage ability of carbon dioxide. In *Blue carbon in shallow coastal ecosystems.* T. Kuwae & M. Hori (Eds.), Springer, Singapore, 2019, pp. 1-31.

Hurlimann, S. How kelp naturally combats global climate change. SITN Blog. Available online: https://sitn.hms.harvard.edu/flash/2019

/how-kelp-naturally-combats-global-climate-change/ (accessed on 2019).

Islam, M.M.; Hoq, M.E.; Ali, M.Z.; Hasan, S.J.; Sharif, A.S.M.; Bhuyan, M.S. Diversity and occurrence of seaweeds from the south-eastern coast of Bangladesh. *Indian Journal of Geo Marine Sciences* **2020**, *49*, 1-10.

Jagtap, A.S.; Meena, S.N. Seaweed farming: A perspective of sustainable agriculture and socio-economic development. In *Natural Resources Conservation and Advances for Sustainability*. Editors Manoj Kumar Jhariya, Ram Swaroop Meena, Arnab Banerjee, Surya Nandan Meena, Elsevier Academic Press, Amsterdam, Netherlands, 2022, pp. 493-501.

Kaladharan, P.; Veena, S.; Vivekanandan, E. Carbon sequestration by a few marine algae: observation and projection. *Journal of the Marine Biological Association of India* **2009**, *51* (1), 107-110.

Kannadhasan, S.; Nagarajan, R. Greenhouse gases: challenges, effect, and climate change. In *Biomass and bioenergy solutions for climate change mitigation and sustainability*. Edited by Ashok Kumar Rathoure and Shankar Mukundrao Khade. IGI Global, 2023, pp. 65-74.

Kim, K.Y. Harnessing seaweed farming for climate mitigation in South Korea: evaluating carbon dioxide removal potential and future research directions. *Algae* **2024**, *39* (4), 329-347. https://doi.org/10.4490/algae.2024.39.10.28

Kinley, R.D.; Fredeen, A.H. In vitro evaluation of feeding North Atlantic stormtoss seaweeds on ruminal digestion. *Journal of Applied Phycology* **2015**, *27* (6), 2387-2393. https://doi.org/10.1007/s10811-014-0487-z

Kinley, R.D.; de Nys, R.; Vucko, M.J.; Machado, L.; Tomkins, N.W. The red macroalgae *Asparagopsis taxiformis* is a potent natural antimethanogenic that reduces methane production during in vitro fermentation with rumen fluid. *Animal Production Science* **2016**, *56* (3), 282-289. http://dx.doi.org/10.1071/AN15576

Kinley, R.D.; Martinez-Fernandez, G.; Matthews, M.K.; de Nys, R.; Magnusson, M.; Tomkins, N.W. Mitigating the carbon footprint and improving productivity of ruminant livestock agriculture using a red seaweed. *Journal of Cleaner production* **2020**, *259*, 120836. http://dx.doi.org/10.1016/j.jclepro.2020.120836

Krause-Jensen, D.; Duarte, C.M. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience* **2016**, *9* (10), 737-742.

Li, X.; Norman, H.C.; Kinley, R.D.; Laurence, M.; Wilmot, M.; Bender, H.; Tomkins, N. *Asparagopsis taxiformis* decreases enteric methane production from sheep. *Animal Production Science* **2016**, *58* (4), 681-688. http://dx.doi.org/10.1071/AN15883

Li, Y. Seaweed Farming-The Cure for Climate Change? Unimelb Blog. Retrieved from https://blogs.unimelb.edu.au/sciencecommunication/2019/09/09/seaweed-farming-the-cure-for-climate-change/ (accesed on 2019).

Machado, L.; Magnusson, M.; Paul, N.A.; de Nys, R.; Tomkins, N. Effects of marine and freshwater macroalgae on in vitro total gas and methane production. *PLoS One* **2014**, *9* (1), e85289. https://doi.org/10.1371/journal.pone.0085289

Machado, L.; Magnusson, M.; Paul, N.A.; Kinley, R.; de Nys, R.; Tomkins, N. Identification of bioactives from the red seaweed *Asparagopsis taxiformis* that promote antimethanogenic activity in vitro. *Journal of Applied Phycology*

2016a, *28* (5), 3117-3126. https://link.springer.com/article/10.1007/s10811-016-0830-7

Machado, L.; Magnusson, M.; Paul, N.A.; Kinley, R.; de Nys, R.; Tomkins, N. Dose-response effects of *Asparagopsis taxiformis* and *Oedogonium* sp. on in vitro fermentation and methane production. *Journal of Applied Phycology* **2016b**, *28* (2), 1443-1452. https://doi.org/10.1007/s10811-015-0639-9

Machado, L.; Tomkins, N.; Magnusson, M.; Midgley, D.J.; de Nys, R.; Rosewarne, C.P. In vitro response of rumen microbiota to the antimethanogenic red macroalga *Asparagopsis taxiformis*. *Microbial Ecology* **2018**, *75* (3), 811-818. https://doi.org/10.1007/s00248-017-1086-8

Magnusson, M.; Vucko, M.J.; Neoh, T.L.; de Nys, R. Using oil immersion to deliver a naturally-derived, stable bromoform product from the red seaweed *Asparagopsis taxiformis*. *Algal Research* **2020**, *51*, 102065. http://dx.doi.org/10.1016/j.algal.2020.102065

Maia, M.R.; Fonseca, A.J.; Oliveira, H.M.; Mendonça, C.; Cabrita, A.R. The potential role of seaweeds in the natural manipulation of rumen fermentation and methane production. *Scientific Reports* **2016**, *6* (1), 1-10. http://dx.doi.org/10.1038/srep32321

Macreadie, P.I.; Costa, M.D.; Atwood, T.B.; Friess, D.A.; Kelleway, J.J.; Kennedy, H.; Duarte, C.M. Blue carbon as a natural climate solution. *Nature Reviews Earth & Environment* **2021**, *2* (12), 826-839. https://doi.org/10.1038/s43017-021-00224-1

Mashoreng, S.; La Nafie, Y.A.; Isyrini, R. Cultivated seaweed carbon sequestration capacity. OPEN ACCESS. IOP Conference Series: Earth and Environmental Science, Volume 370, The 2nd International Symposium on Marine Science and Fisheries (ISMF2) - 2019 22 June 2019, Makassar, Indonesia. IOP Publishing. https://iopscience.iop.org/article/10.1088/1755-1315/370/1/012017

McGregor, A.; Rickards, L.; Houston, D.; Goodman, M.K.; Bojovic, M. The biopolitics of cattle methane emissions reduction: governing life in a time of climate change. *Antipode* **2021**, *53* (4), 1161-1185. https://doi.org/10.1111/anti.12714

Min, B.R.; Parker, D.; Brauer, D.; Waldrip, H.; Lockard, C.; Hales, K.; Augyte, S. The role of seaweed as a potential dietary supplementation for enteric methane mitigation in ruminants: Challenges and opportunities. *Animal Nutrition* **2021**, *7* (4), 1371-1387. https://doi.org/10.1016/j.aninu.2021.10.003

Minich, J.J.; Morris, M.M.; Brown, M.; Doane, M.; Edwards, M.S.; Michael, T.P.; Dinsdale, E.A. Elevated temperature drives kelp microbiome dysbiosis, while elevated carbon dioxide induces water microbiome disruption. *PLoS One* **2018**, *13* (2), e0192772. https://doi.org/10.1371/journal.pone.0192772

Oni, A.O.; Giwa, T.; Font-Palma, C.; Fadare, D.A. Comparative techno-economic and life cycle greenhouse gas assessment of ammonia production from thermal decomposition of methane and steam methane reforming technologies. *International Journal of Greenhouse Gas Control* **2023**, *123*, 103819. https://doi.org/10.1016/j.ijggc.2022.103819

Osorio, L.K.P. Physiological responses, bioactivity and differential analysis of protein abundance of the brown seaweed *Sargassum* (Phaeophyceae, Fucales) submitted to UV radiation (Doctoral dissertation, Universidade de São Paulo), 2019.

Packer, M. Algal capture of carbon dioxide; biomass generation as a tool for greenhouse gas mitigation with reference to New Zealand energy strategy and policy. *Energy policy* **2009**, *37* (9), 3428-3437. https://doi.org/10.1016/j.enpol.2008.12.025

Perring, M.P.; Aberg, D.; Harley, J.; Dunn, C.; Garbutt, A. Nutrient removal processes in saltmarsh and adjacent habitats: overview and a preliminary study of denitrification in the Solent, UK. 2025. https://nora.nerc.ac.uk/id/eprint/538761

Prayitno, C.H.; Utami, F.K.; Nugroho, A.; Widyastuti, T. The effect of seaweed (*Gracilaria* sp.) supplementation in sheep feed on methanogenesis inhibition in vitro. 1st International Conference of Animal Science and Technology (ICAST) 2018. IOP Conference Series: Earth and Environmental Science 247 (p. 012069). IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/247/1/012069

Ramin, M.; Franco, M.; Roleda, M.Y.; Aasen, I.M.; Hetta, M.; Steinshamn, H. In vitro evaluation of utilisable crude protein and methane production for a diet in which grass silage was replaced by different levels and fractions of extracted seaweed proteins. *Animal Feed Science and Technology* **2019**, *255*, 114225. https://doi.org/10.1016/j.anifeedsci.2019.114225

Roque, B.M.; Brooke, C.G.; Ladau, J.; Polley, T.; Marsh, L.J.; Najafi, N.; Hess, M. Effect of the macroalgae *Asparagopsis taxiformis* on methane production and rumen microbiome assemblage. *Animal Microbiome* **2019**, *1* (1), 1-14. https://doi.org/10.1186/s42523-019-0004-4

Roque, B.M.; Venegas, M.; Kinley, R.D.; de Nys, R.; Duarte, T.L.; Yang, X.; Kebreab, E. Red seaweed (*Asparagopsis taxiformis*) supplementation reduces enteric methane by over 80 percent in beef steers. *Plos one* **2021**, *16* (3), e0247820. https://doi.org/10.1371/journal.pone.0247820

Sahoo, D.; Elangbam, G.; Devi, S.S. Using algae for carbon dioxide capture and bio-fuel production to combat climate change. *Phykos* **2012**, *42* (1), 32-38.

Sondak, C.F.; Ang, P.O.; Beardall, J.; Bellgrove, A.; Boo, S.M.; Gerung, G.S.; Chung, I.K. Carbon dioxide mitigation potential of seaweed aquaculture beds (SABs). *Journal of Applied Phycology* **2017**, *29* (5), 2363-2373. https://doi.org/10.1007/s10811-016-1022-1

Sonwani, S.; Saxena, P. *Greenhouse gases: sources, sinks and mitigation*, 1st Edition. Saurabh Sonwani, Pallavi Saxena Eds, Springer Nature Singapore, Singapore, 2022.

Sovacool, B.K.; Griffiths, S.; Kim, J.; Bazilian, M. Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions. *Renewable and Sustainable Energy Reviews* **2021**, *141*, 110759. https://doi.org/10.1016/j.rser.2021.110759

SJSU. Seaweed Aquaculture & Bromomethane Emissions. Available online: https://mlml.sjsu.edu/chemoce/seaweed-bromoform/ (accessed on 2022).

Sun, T.; Ocko, I.B.; Sturcken, E.; Hamburg, S.P. Path to net zero is critical to climate outcome. *Scientific Reports* **2021**, *11* (1), 1-10. https://doi.org/10.1038/s41598-021-01639-y

Thomson, L. Seaweed's potential in tackling climate change. AZOCLEANTECH. Available online: https://www.azocleantech.com/article.aspx?ArticleID=1347 (accessed on 3 Novemver 2021).

Vega, J.; Catalá, T.S.; García-Márquez, J.; Speidel, L.G.; Arijo, S.; Cornelius Kunz, N.; Figueroa, F.L. Molecular diversity and biochemical content in two invasive alien species: Looking for chemical similarities and bioactivities. *Marine Drugs* **2023**, *21* (1), 5. https://doi.org/10.3390/md21010005

Vijn, S.; Compart, D.P.; Dutta, N.; Foukis, A.; Hess, M.; Hristov, A.N.; Kurt, T.D. Key considerations for the use of seaweed to reduce enteric methane emissions from cattle. *Frontiers in Veterinary Science* **2020**, *7*, 1135. https://doi.org/10.3389/fvets.2020.597430

Wang, K.; Xiong, B.; Zhao, X. Could propionate formation be used to reduce enteric methane emission in ruminants? *Science of the Total Environment* **2023**, *855*, 158867. https://doi.org/10.1016/j.scitotenv.2022.158867

Wang, Y.; Xu, Z.; Bach, S.J.; McAllister, T.A. Effects of phlorotannins from *Ascophyllum nodosum* (brown seaweed) on in vitro ruminal digestion of mixed forage or barley grain. *Animal Feed Science and Technology* **2008**, *145* (1-4), 375-395. https://doi.org/10.1016/j.anifeedsci.2007.03.013

Webb, R.; Silverman-Roati, K.; Gerrard, M. Removing carbon dioxide through ocean alkalinity enhancement and seaweed cultivation: Legal challenges and opportunities. Sabin Center for Climate Change Law, Columbia Law School, Columbia Public Law Research Paper Forthcoming, 2021.

Woody, T. National Geographic. Seaweed 'forests' can help fight climate change. Available online: https://www.nationalgeographic.com/environment/article/forests-of-seaweed-can-help-climate-change-without-fire (accessed on 29August 2019).

Work, T. Global Seafood. The current state of seaweed: Part II. Available online: https://www.globalseafood.org/blog/seaweed-aquaculture-benefits/ (accessed on 2017).

Yong, W.T.L.; Thien, V.Y.; Rupert, R.; Rodrigues, K.F. Seaweed: A potential climate change solution. *Renewable and Sustainable Energy Reviews* **2022**, *159*, 112222. https://doi.org/10.1016/j.rser.2022.112222

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