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Assessment Carbon Sequestration Rate of Different Cultivable Seaweeds of Cox's Bazar Coast, Bangladesh

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Abstract

Seaweed has the ability to use carbon from the environment through photosynthesis to produce biomass. This study aims to estimate the carbon sequestration rate by different cultivable seaweeds as a strategy to mitigate the impact of ocean acidification and global climate change. This study also determines the influence of carbon sequestration on different environmental factors. The study was undertaken at Cox's Bazar coast. Locally available five seaweed species namely *Gracilaria tenuistipitata*, *Ulva compressa*, *U. intestinalis, U. lactuca* and *polysiphonia sp*. were cultured with the longline and net method for three cultivation periods, starting from October to March, 2020-2021. Each cultivation period was taken about 45 days. Seaweed samples were collected every 15 days from day 0 (initial), 15,30 to 45 (replanting) for every cultivation period to assess the carbon content of seaweeds. The results show that the sequestration rate of *U. intestinalis* is significantly higher than the others in the longline and net method. Highest concentration found in the day-45 and lowest concentration is in the day-15. Descending order of the Carbon sequestration in the cultivated seaweeds *U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia sp*. Trends of carbon sequestration rate were influenced by different seaweed variants. Generally, *U. intestinalis* has higher sequestration rate than other four seaweed variants. Highest concentration found in the day 45 and lowest concentration is in the day 15. Two way-ANOVA results showed the comparisons of the rate of the carbon sequestration among the different cultivated seaweeds at Cox's Bazar coast among different stations and seasons. Correlation matrix and multiple regression analysis showed the influence of different environmental factors. If the cultures of seaweed increases worldwide in a large scale it will be a powerful tool in controlling ocean acidification and economically benefitted.

Keywords: Blue carbon; Seaweed; Climate change; Post-monsoon; Pre-monsoon; Winter

Introduction

Seaweeds are marine macro algae and primitive types of plants, growing abundantly in the shallow waters of the sea, estuaries and backwaters. They flourish wherever rocky, coral or suitable substrata are available for their attachment. They are distributed along coasts from tropical to Polar Regions. They are part of the plantae kingdom and like land plants, seaweed also constitutes the basis of the food chain but in aquatic ecosystems. Among the major primary producers, seaweeds or benthic marine algae grow in the inter-tidal and sub-tidal regions of the sea and contain photosynthetic pigments, which lead them to photosynthesize and produce food. Seaweeds are grouped in three divisions: Brown algae (*Ocrophyta-Phaeophyceae*), Red algae (*Rhodophyta*), and Green algae (*Chlorophyta*). Among seaweed species, the number of red, brown and green seaweed species is 6000, 2000, 1200 respectively.

Seaweeds have been used since ancient times as food, fooder and fertilizer and as a source of medicinal drugs, today seaweeds are the raw material for industrial production of agar, algin, and carrageenan but they continue to be widely consumed as food in Asian countries. They are nutritionally valuable as fresh or dried vegetables, or as ingredients in a wide variety of prepared foods. In particular, certain edible seaweeds contain significant quantities of lipid, protein, vitamins and minerals, although nutrient contents vary with species, geographical location, season and temperature.

CO_2 is the main anthropogenic greenhouse gas, if that released into the atmosphere, is responsible for increasing the greenhouse effect leading to global warming. Climate change is caused by the massive increase of GHG (Green House Gases) emission to the atmosphere, for example CO_2, which is caused not only from neutral factors but also from human activities (anthropogenic factors) including the burning of fossil fuels and deforestation. The impact of climate change on marine environment is already apparent, such as sea level rise, ocean surface warming, changing course of currents, acidification of surface waters and shifting ranges of natural species.

Climate change mitigation is an important role of seaweed. The impact of climate change on seaweed abundance, distribution and quality is a global concern. Seaweed has a certain degree of resilience to global climate change and its biomass availability can vary on a spatial basis [1,2]. Seaweed acts as a sponge for carbon dioxide and reducing ocean acidification. *Gracilaria tikvahiae* (red seaweed) and *Saccharina latissima* (brown seaweed) assimilate carbon rapidly in Long Island Sound and the Bronx River Estuary of New York reported that if 0.03% ocean surface area can be cultured then it will be able to remove about 135 million tons of carbon from the ocean water. That means it will remove approximately 3.2% of carbon annually inputted to ocean water from the atmosphere.

CO_2 gas is present in considerably higher concentrations in seawater (34-56 ml/l) than in the atmosphere (0.3 ml/l), partially due to the ability of water to absorb more CO_2 than air, in equal volume. There has been a good deal of interest in the potential of marine vegetation as a sink for anthropogenic carbon emissions which is known as blue carbon. The concept of blue carbon or atmospheric carbon captured by coastal ecosystems has recently been the focus of reports by UNEP (the United Nations Environment Programme) and IUCN (the International Union for the Conservation of Nature). Seaweed is potential marine vegetation that can use solar energy for the bio-fixation of concentrated CO_2 sources from the atmosphere into biomass that can be used to produce phycocolloid compound. These macroalage have the relatively better capability on carbon sequestration than terrestrial plants.

Mass cultivation of seaweeds can be more effective method for CO_2 capture and sequestration from the environment because CO_2 can be transformed and become more valuable products through photosynthesis. The rate of carbon sequestration by seaweeds would vary depending on the type of seaweed and the climatic conditions in which it was grown.

Human activities have resulted in significant greenhouse gas emissions. Between 1980 and 1989, CO_2 emissions from fossil-fuel combustion and tropical deforestation totaled to 7.1 billion tonnes of carbon emitted each year. Carbon dioxide concentration increases in the atmosphere could account for around half of CO_2 emissions over this time period.

The ocean has also absorbed huge amounts of human CO_2; the quantity of CO_2 uptake by the ocean is estimated to be 2 billion tonnes of carbon each year, according to the IPCC (Intergovernmental Panel on Climate Change).

In various parts of Southeast Asia, such as Thailand, the Philippines, Malaysia, and Indonesia, seaweed culture is booming. According to FAO, global seaweed output is expected to be 6 million tonnes per year, worth over $5 billion dollars, with farmed seaweeds accounting for nearly 5% of total global fisheries production. Seaweed aquaculture, the fastest-growing component of global food production, offers a slate of opportunities to mitigate and adapt to climate change. Seaweed farms release carbon that may be buried in sediments or exported to the deep sea, therefore acting as a CO_2 sink. The crop can also be used, in total or in part, for biofuel production, with a potential CO_2 mitigation capacity, in terms of avoided emissions from fossil fuels, of about 1,500 tons CO_2 km^{-2} $year^{-1}$. Seaweed aquaculture can also help reduce the emissions from agriculture, by improving soil quality substituting synthetic fertilizer and when included in cattle fed, lowering methane emissions from cattle.

Seaweed aquaculture contributes to climate change adaptation by damping wave energy and protecting shorelines and by elevating pH and supplying oxygen to the waters, thereby locally reducing the effects of ocean acidification and de-oxygenation. The scope to expand seaweed aquaculture is, however, limited by the availability of suitable areas and competition for suitable areas with other uses, engineering systems capable of coping with rough conditions offshore and increasing market demand for seaweed products, among other factors. Despite these limitations, seaweed farming practices can be optimized to maximize climate benefits, which may if economically compensated, improve the income of seaweed farmers.

With an annual production of 27.3 million tons in 2014 and a growth rate of 8% $year^{-1}$, seaweed aquaculture now comprises 27% of total marine aquaculture production. Still, the value of the seaweed produced only amounts to 5% of the total value of aquacultural crops (FAO, 2016a). Looking at the process chain of seaweed from production through processing to final products, the growth of the actual seaweed production lags behind the demand of biomass for the many traditional and novel applications for this expanding crop [3,4]. Further expansion of seaweed aquaculture will require the development of a skilled labor force and new technologies to occupy additional suitable areas for farming. Also, diversification of applications will make the industry more resilient to impacts derived from shifting demands from specific industries. A closer synergy between the further expansion of seaweed aquaculture and the development of novel demands for this crop will be essential to continue to fuel the growth of this emerging blue industry. Compensating farmers for the role of seaweed production in climate change mitigation and adaptation need also be considered. Indeed, an increased contribution of seaweed aquaculture to climate change mitigation and adaptation requires that seaweed production continues to grow. However, further growth of seaweed production may drive market prices down, in turn discouraging farmers from engaging in this activity. Thus, providing economic incentives associated with the benefits of climate change mitigation and adaptation may be instrumental in supporting increased seaweed production into the future.

Seaweed production, both from wild stocks and from aquaculture, represents an important conduit for CO_2 removal from the atmosphere, with strongly autotrophic seaweed communities globally taking up 1.5 Pg C $year^{-1}$ *via* their net production [5]. Yet, the potential of managing seaweed production to mitigate climate change by sequestering CO_2 has not yet been fully incorporated into the emergent concept of Blue Carbon, referring to climate change mitigation strategies based on the capacity of marine plants to bind CO_2 [6-8]. The reason for such neglect is the belief that the large majority of seaweed production is decomposed in the ocean and therefore, does not represent a net sink for CO_2. However, this view has been recently challenged [9,10] and new evidence suggests that seaweeds are globally-relevant contributors to oceanic carbon sinks [11]. Hence, the contribution of seaweed to Blue Carbon and climate change mitigation strategies is now being reconsidered.

One pathway to broaden Blue Carbon strategies to incorporate the CO2 sink capacity of seaweeds is to manage the fate of seaweed production, whether derived from aquaculture or harvest of wild stocks, to reduce CO_2 emissions derived from fossil fuel use. This can be achieved, for instance, through the use of seaweed biomass as biofuel directly replacing fossil fuels [12,13] and/or replacing food or feed production systems with intense CO_2 emission footprints with seaweed-based food systems, which have much lower life-cycle CO_2 emission [14]. Indeed, a seaweed-based Blue Carbon program has been developed in Korea [15,16], providing an initial step in this direction. Yet, Korea contributes only 6% of global seaweed aquaculture production (FAO, 2016b), so the development of seaweed farming as a Blue Carbon strategy for climate change mitigation would require that major producers, such as China accounting for more than half of the global seaweed aquaculture production, engage with this strategy.

The development of seaweed farming as a strategy for climate change mitigation would help alleviate present constraints on the further growth of seaweed aquaculture. The growth of seaweed production is exceeding that of traditional markets, leading to a steady decline in price at about 1–2% $year^{-1}$ [17], deterring farmers and investors from engaging. Economic compensation for the environmental benefits brought about by seaweed farming, including its role in climate change mitigation, would allow for further growth and a more sustainable seaweed aquaculture industry. In particular, economic compensation for climate services associated with seaweed farming would help generate a new market for seaweed production while also creating incentives to reduce further the life-cycle CO_2 emissions of seaweed aquaculture.

Here we outline the potential to develop seaweed Blue Carbon Farming as a strategy for climate change mitigation and adaptation. We do so by first assessing the potential, based on wild and aquaculture production and the pathways for this production to be managed as to result in avoidance of CO_2 emissions while possibly generating climate change adaptation co-benefits.

We then evaluate the role of seaweed aquaculture in adaptation to specific impacts of climate change in the marine environment, such as ocean acidification, deoxygenation and shoreline erosion [18]. Finally, we propose a number of actions required to consolidate such a program as a component of the pathway to solutions for climate change adaptation and mitigation.

Objectives of the study

To assess the carbon sequestration rate of cultivable seaweed this can mitigate the impact of ocean acidification and global climate change.

To show the comparison of carbon sequestration of different cultivable seaweeds between long line and net methods.

To show the relationships among the environmental factors and the rate of carbon sequestration of different cultivable seaweeds at Cox's Bazar coast.

To know about the physio-chemical parameters comparison with the Carbon sequestration among different cultivable seaweeds of the study area.

Materials and Methods

Study area

The present study was located in the south-eastern coastal waters of Bangladesh, particularly in the Cox's Bazar coast at Nuniarchara and Rezukhal (Figures 1 and 2).

For measuring the carbon sequestration of different cultivable seaweeds, the experiment was set up at the mid-inter-tidal zone of Nuniarchara (21°28.26´ 31" N, 91°57.51´24" E) coast and the mouth of Rezukhal (21°18.6´64" N, 92°2.41´60" E) in Cox's Bazar. The Nuniarchara coast is bordered on the northwest by one of the country's busy Moheskhali channels. On the other hand, Rezukhal is situated in the southern portion of the country and directly open into the ocean.

Two control/reference sites were set associated with the culture site in order to measure the ecological benefits and environmental risks of seaweed cultivation at the Cox's Bazar coastal area.

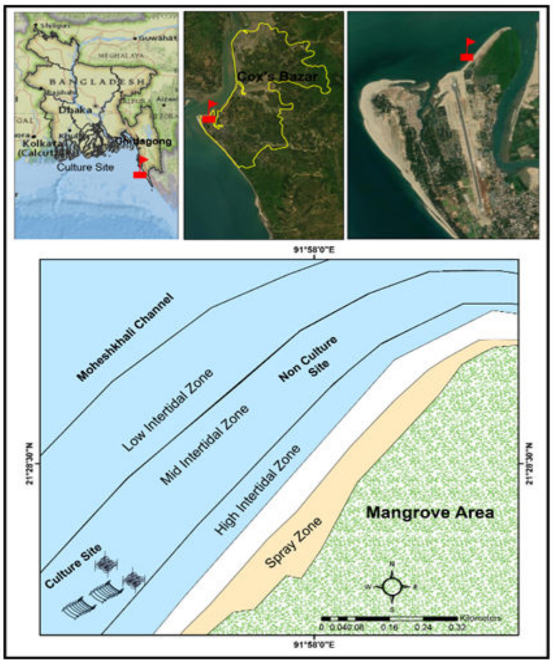

Figure 1: Seaweed culture and non-culture site at Nuniarchara.

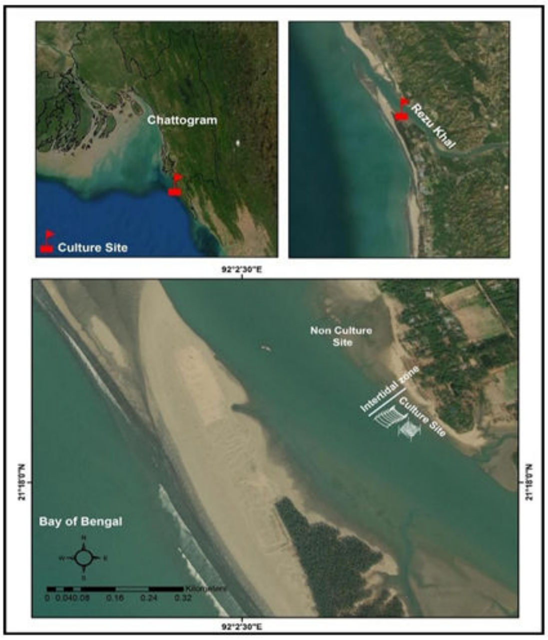

Figure 2: Seaweed culture and non-culture site at Rezu Khal.

Seaweed culture period

The culture period was started from mid-October to mid of March. Three experimental cycles was performed (Table 1).

Cycle	Plant	Harvest	Date
1st	24-Oct	08-Dec	24.10.2020-08.12.2020
2nd	08-Dec	22-Jan	08.12.2020-22.01.2021
3rd	22-Jan	08-Mar	22.01.2021-08.03.2021

Table 1: Cultivation period of seaweed species.

Seaweed is a seasonal product and so it is available during the winter season. So, we planted the seaweeds at the mid of October and it was completed at the mid of March.

Selected species

In this study, naturally available five seaweed species (*Gracilaria tenuistipitata, Ulva lactuca, U. compressa, U. intestinalis and Polysiphonia sp.*) were used for cultivation. Two different methods namely long-line and net methods used for cultivation. Young growing fragments of the seaweeds were collected from Nuniarchara and used as initial seedlings. The seedling was done by inserting the young fragments of seaweeds among the rope twisters at 20 cm intervals.

Seaweed planting

Poly Vinyl Chloride (PVC) rope is used for attaching seaweed seed (seaweed filament). Seaweed was attached in a rope knot with a weight of 10 grams in each knot after an interval of 20 cm from one knot to another. Plastic floats were used to float the seaweeds.

Experimental setting

Seaweed culture sites were prepared using plastics rope for long lines and coir rope for the net. The size of the long line unit was 15 × 6 m^2 which consists of 4 lines/unit. Locally available PVC (plastic) (12 mm) rope was used for the long line. Long line was tied up with bamboo poles tightly and the plastic float was used to hold the line in high tide with bamboo poles so that the setting can stand during high tide. Plastic floats were placed 25 cm above the bottom (Figure 3).

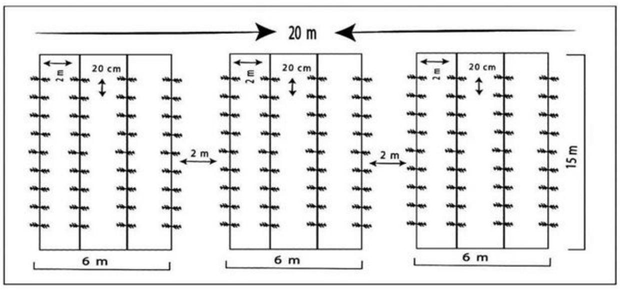

Figure 3: Schematic Model of Experimental setting.

Data collection

Different types of methods are widely employed in seaweed cultivation. Among them are the "Longline method and Net method" where seaweeds are cultivated on suspended lines or ropes. For the present culture experiment, 15 m long line ropes were stretched perpendicularly with the shore. There are 10 linear ropes, 2 lines for one species, as we cultivated 5 species, there were 10 ropes with 137 cm intervals in a plot, and each linear rope was anchored by two bamboo poles on two opposite sides. 2-3 plastic floats were attached with ropes which help them to hover or stay afloat in the water during high tides.

Young seedlings of 8-10 gm in weight and 10-11 cm in length were collected for the initial seedlings. These young seedlings inserted very carefully in the twist of the rope.

Locally available five-seaweed species namely *Gracilaria tenuistipitata, Ulva compressa, U. Intestanalis, U. lactuca and Polysiphonia sp.* were cultured for measuring carbon sequestration rate in this experiment. The sample was collected every 15 days from day 0 (initial), 15, 30, to 45 (replanting) for every cultivation period. Seaweeds samples were washed and sorted out thoroughly to remove adhered epiphytes or sand and brought to the Institute of Marine Sciences (IMS), University of Chittagong (CU). In the laboratory, samples were gently brushed under running seawater, rinse with distilled water, dried, grind the sample into powder and finally preserved into the airtight vial.

Data calculation

At the subsequent stage the processed sample was stored at -20℃ in the freezer (AOAC manual are followed) and the Carbon Content-were analyzed according to loss of weight on ignition method (FAO, 2008) in IMS, CU laboratory. Finally, the carbon sequestration rate (ton C/m^2/year) was estimated by using the formula as follows [19].

Cseq=A × S × P-B ratio × Ccont.

Where, A is a total wide area of seaweed cultivation (m^2), S is standing stock (g/m^2), P-B ratio is the production-biomass ratio and Ccont is the carbon content (%) [20-25].

Data analysis

All the carbon sequestration data in the present study were expressed in terms of mean ± standard deviation and range [26-30]. Spatio-temporal variations in the value of carbon sequestration rate of different cultivable seaweeds were presented in tabular and graphical form. Variations in the carbon sequestration rate in different cultivable species, seasons, and stations were tested by one-way and two-way ANOVA followed by post hoc Studente Newmane Keuls's test (a=0.05). The Pearson coefficient (r) was calculated to determine the linear relation between the variables. Statistical analyses were performed with SPSS software (version 23.0). Data analysis was also performed by Microsoft Office Excel [31-35].

Results

The carbon sequestration rate of different cultivable seaweeds at Cox's Bazar coast using different methods in different seasons and stations was presented in Table 6. This study showed that the sequestration rate of *U. intestanalis* is significantly higher than the others while the species was cultured in longline method [36-40]. The highest concentration is found on day-45 and the lowest concentration is on day 15. Descending order of the carbon sequestration in the cultivated seaweeds *U. intestanalis> U. compressa> G. tenuistipitata> U. lactuca> Polysiphonia sp.* (Table 2 and Figure 4). Similarly, the rate of carbon sequestration by *U. intestanalis* is higher than the others while it was cultured in Nuniarchora using net method (Table 2 and Figure 5).

The highest concentration is found on day-45 and the lowest concentration is on day-15. Descending order of the Carbon sequestration in the cultivated seaweeds *U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia sp.* The carbon sequestration rate of different cultivable seaweeds cultured in the Rezukhal site using different methods were presented in Table 2, Figure 6 and Figure 7. Two way-ANOVA results for the comparisons of the rate of the carbon sequestration among the different cultivated seaweeds at Cox's Bazar coast among different stations and seasons were presented in Table 2.

Name of the sites	Species	Method	Seasons		
			Post-monsoon	Winter	Pre-monsoon
Nuniarchara	*Gracilaria*	Longline	331.40 ± 202.72	280.37 ± 173.47	525.63 ± 382.08
	tenuispitata	Net	248.99 ± 151.43	247.70 ± 150.83	334.25 ± 221.87
	Ulva compressa	Longline		827.56 ± 555.93	724.38 ± 518.65
		Net		417.30 ± 242.99	432.96 ± 305.87
	Ulva intestinalis	Longline		1396.68 ± 961.91	1217.71 ± 899.18
		Net		956.24 ± 609.38	861.95 ± 582.62
	Ulva lactuca	Longline		140.72 ± 84.92	239.83 ± 166.76
		Net		135.28 ± 79.16	259.39 ± 174.45
	Polysiphonia sp.	Longline		104.92 ± 54.37	
		Net		101.14 ± 50.92	
Rezukhal	*Gracilaria*	Longline	336.91 ± 210.02	338.22 ± 209.92	334.26 ± 207.82
	tenuispitata	Net	238.39±146.32	238.51 ± 146.48	237.85 ± 146.28
	Ulva compressa	Longline		540.75 ± 341.46	
		Net		396.62 ± 251.53	
	Ulva intestinalis	Longline		869.07 ± 660.45	742.26 ± 568.69
		Net		694.59±517.77	590.45±465.45
	Ulva lactuca	Longline		136.98±93.23	193.77±124.76
		Net		123.39 ± 75.25	167.94 ± 109.55
	Polysiphonia sp.	Longline		100.29 ± 50.95	
		Net		104.6 ± 54.88	

Table 2: Rate of Carbon sequestration (ton C/m^2/year) of different seaweed species cultivated at different area of Cox's Bazar coast using different methods.

U. intestinalis showed the highest carbon concentration and *U. lactuca and polysiphonia sp.* showed the lowest carbon concentration in the longline method at Nuniarchara. *U. intestinalis* showed the highest concentration during the winter season. The winter season is most important for all the species for absorbing most carbon [41-45]. In post-monsoon, carbon sequestration is less in the amount in the 5 seaweeds species. In the longline method at Nuniarchara, the overall descending order of seaweed species is *U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia sp.* (Figure 4).

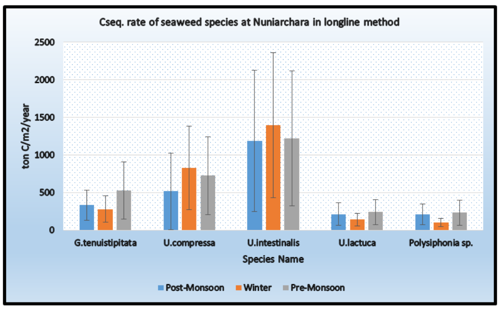

Figure 4: Carbon sequestration rate of the different cultivated seaweed species at Nuniarchara culture site during the study period using longline method.

U.intestinalis showed highest carbon concentration and *polysiphonia sp.* showed lowest carbon concentration in the net method at Nuniarchara. *U.intestinalis* showed highest concentration during winter season. Winter season is mostly important for all the species for absorbing most carbon. In post-monsoon, carbon sequestration is less in amount in the 5 seaweeds species.In the net method at Nuniarchara the overall descending order of seaweed species is- *U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia* sp. (Figure 5).

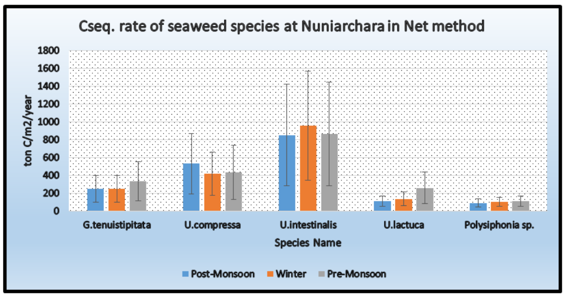

Figure 5: Carbon sequestration rate of the different cultivated seaweed species at Nuniarchara culture site during the study period using net method.

U. intestinalis showed highest carbon concentration and polysiphonia sp. showed lowest carbon concentration in the long line method at Rezukhal. U. intestinalis showed highest concentration during winter season [46-50]. Winter season is mostly important for all the species for absorbing most carbon.In post-monsoon, carbon sequestration is less in amount in the 5 seaweeds species. In the longline method at Rezukhal the overall descending order of seaweed species is U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia sp. (Figure 6).

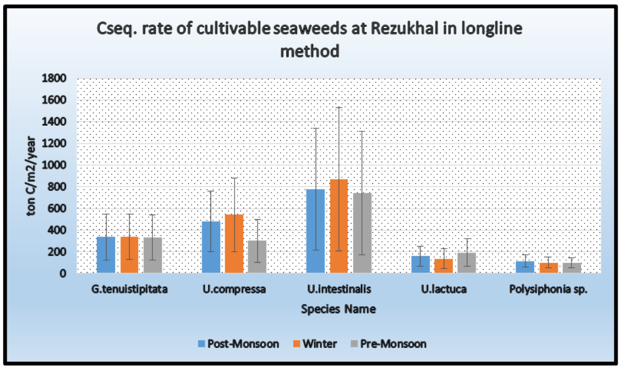

Figure 6: Carbon sequestration rate of the different cultivated seaweed species at Rezu khal culture site during the study period using longline method.

U.intestinalis showed highest carbon concentration and *polysiphonia sp.* showed lowest carbon concentration in the net method at Rezukhal. *U. intestinalis* showed highest concentration during winter season. Winter season and pre-monsoon are mostly important for all the species for absorbing most carbon. In post-monsoon, carbon sequestration is less in amount in the 5 seaweeds species. In the net method at Nuniarchara the overall descending order of seaweed species is *U. intestanalis>U. compressa>G. tenuistipitata>U. lactuca>Polysiphonia sp.* (Figure 7).

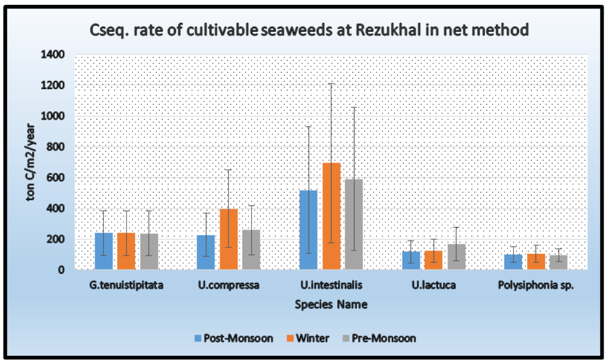

Figure 7: Carbon sequestration rate of different cultivated seaweed species at Rezu Khal culture site during the study period using net method.

Carbon sequestration was highest in *U. intestinalis* at Nuniarchara longline method and lowest in Rezukhal net method *G. tenuistipitata* absorbs most carbon in Rezukhal Longline and lowest in Rezukhal net method *U. compressa* was highest in Nuniarchara longline and lowest in Rezukhal net *U. intestinalis* was highest in Nuniarchara longline and lowest in Rezukhal net *U. lactuca* was highest in Nuniarchara net and *Polysiphonia sp* was highest in Rezukhal longline [51-55]. Here, Overall in Post-monsoon, longline method is better than the net method and Nuniarchara is more productive than Rezukhal (Figure 8).

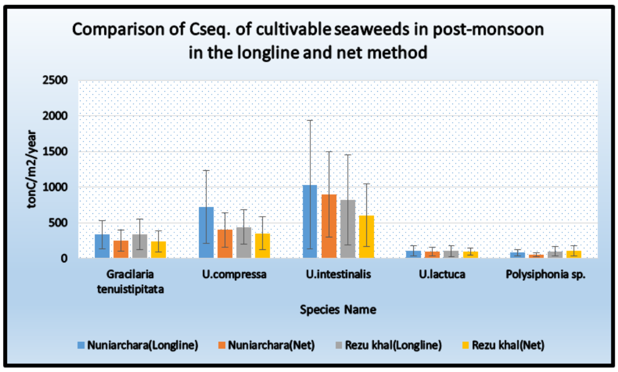

Figure 8: Comparison of Carbon sequestration rate of different cultivable seaweeds in post-monsoon in the longline and net method.

Carbon sequestration was highest in U.intestinalis at Nuniarchara longline method and lowest in Rezukhal net method. *G. tenuistipitata* absorbs most carbon in Rezukhal Longline and lowest in Rezukhal net method *U. compressa* was highest in Nuniarchara longline and lowest in Rezukhal net *U. intestinalis* was highest in Nuniarchara longline and lowest in Rezukhal net *U. lactuca* was highest in Nuniarchara longline and Polysiphonia sp was highest in Nuniarchara longline. Here, Overall in winter, longline method is better than the net method and Nuniarchara is more productive than Rezukhal (Figure 9).

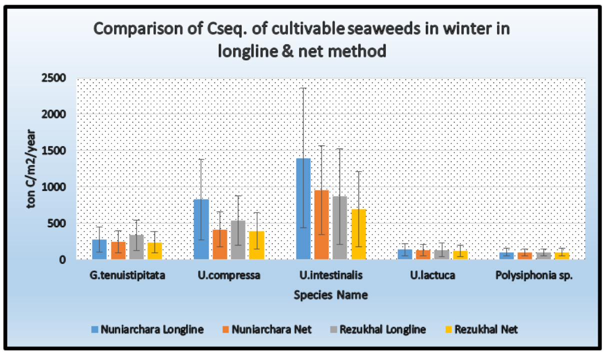

Figure 9: Comparison of carbon sequestration rate of different cultivable seaweeds in winter in the long line and net method.

Carbon sequestration was highest in *U. intestinalis* at Nuniarchara longline method and lowest in Rezukhal net method *G. tenuistipitata* absorbs most carbon in Nuniarchara Longline and lowest in Rezukhal net method. *U. compressa* was highest in Nuniarchara longline and lowest in Nuniarchara net *U. intestinalis* was highest in Nuniarchara longline and lowest in Rezukhal net *U. lactuca* was highest in Nuniarchara net and *Polysiphonia sp*. was highest in Nuniarchara longline. Here, Overall in Pre-monsoon, longline method is better than the net method (Figure 10).

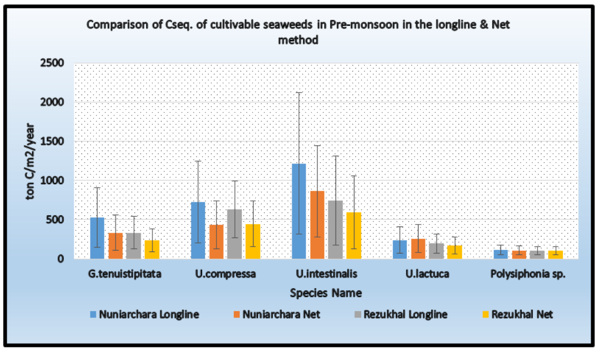

Figure 10: Comparison of carbon sequestration rate of different cultivable seaweeds in Post-monsoon in the long line and net method.

Relationships among the environmental factors and the rate of carbon sequestration of different cultivable seaweeds at Cox's Bazar coast were presented in Table 3.

Factor	*G. tenuistipitata*	*U. compressa*	*U. intestinalis*	*U. lactuca*	*Polysiphonia sp.*
DO	-.155*	.284*	.379**	-0.206	.796**
pH	.405**	-0.231	-.302**	.289*	0.017
TDS	.475**	.253*	0.224	.764**	.808**
Conductivity	.431**	0.23	0.201	.703**	.901**
Salinity	.373**	0.073	0.032	.472**	.649**
Density	.408**	.273*	-.241*	.681**	.905**
Temperature	.280**	0.13	0.047	.684**	-0.057
Transparency	-.380**	-.250*	-0.187	-.752**	-.968**

Table 3: Correlation matrix among the environmental factors and rate of the carbon sequestration of different cultivable seaweeds at Cox's Bazar coast.

The influence of different environmental factors on the carbon sequestration rate of different cultivated seaweeds at Cox's Bazar coast were depicted in Table 4.

Factor	*G. tenuistipitata*	*U. compressa*	*U. intestinalis*	*U. lactuca*	*Polysiphonia sp.*
DO	0.096	.872**	1.147**	0.241	.268**
pH	-0.183	-.746**	-.837**	-0.56	-.076*
TDS	1.354*	1.039**	1.383**	1.730**	-0.355
Conductivity	-1.869**	0.45	1.226*	-0.188	1.800**
Salinity	-2.224**	0.304	0.685	-0.144	0.011
Density	3.506**	-1.96	-3.515**	-1.031	0.475
Temperature	.667**	0.262	-0.036	-169	-.469*
Transparency	-0.03	-1.128*	-1.605**	-1.088**	0.612
**1% level of significance;*5% level of significance with ß-coefficients values derived from the multiple regression models.					

Table 4: Multiple regression analysis for showing the influence of different environmental factors on the rate of carbon sequestration of different cultivable seaweeds at Cox's Bazar coast.

A correlation matrix of eight parameters namely DO, pH, TDS, Conductivity, Salinity, Density, Temperature and Transparency was constructed. The correlation coefficient always measures the relationship between the dependent and independent variables. If the correlation coefficient is +1 to -1, it shows the perfect linear relationship between variables. *G. tenuistipitata* showed a negative correlation with DO and transparency, showed a significant positive correlation with pH, TDS, conductivity, salinity, density, and temperature. *U. compressa* also had a significant positive correlation with DO, TDS, conductivity, salinity, density and temperature, negative correlation with pH and transparency. *U. intestinalis* showed a significant positive correlation with DO, TDS, conductivity, salinity and temperature, negative correlation with pH, density, and transparency [56]. *U. lactuca* showed a significant positive correlation with pH, TDS, conductivity, Salinity, Density, and temperature, negative correlation with DO and transparency. *Polysiphonia sp*. showed a positive correlation with DO, pH, TDS, conductivity, salinity, density, negative correlation with temperature and transparency (Table 3).

Multiple regression analysis showed the influence of different environmental factors on the rate of carbon sequestration of different cultivable seaweeds at Cox's Bazar coast. G. tenuistipitata was positively influenced by density and temperature and negatively influenced by conductivity and salinity at 1% level of significance; TDS positively affect the G. tenuistipitata at 5% level of significance. U. compressa was positively influenced by DO and TDS, negatively influenced by pH at 1% level of significance [57].

Transparency negatively influenced U. compressa at 5% level of significance. U. intestinalis was positively influenced by DO, TDS and negatively influenced with pH, density and transparency at 5% level of significance. U. lactuca was positively influenced by TDS and negatively by transparency at 5% level of significance. *Polysiphonia sp*. positively influenced by DO and conductivity at 5% level of significance and negatively influenced by the temperature at 1% level of significance (Table 4).

Discussion

The capability of four seaweed variants on carbon sequestration was described with the range of carbon sequestration rates. Analyses of variance and Dunean Test showed that seaweed variants indicated significant difference ($P<0.05$) in influencing seaweed ability on carbon sequestration, either the maximum or minimum values [58-62].

We cultivated 5 different seaweeds in two different methods in two stations (Nuniarchara and Rezukhal). Polysiphonia sp. had the lowest minimum value of carbon sequestration than *G. tenuistipitata*, *U. compressa*, *U. intestinalis*, *U. lactuca* about 104.6-54.88 ton C/m^2/year in Nuniarchara in longline method.

While *U.intestinalis* showed the highest maximum value of carbon sequestration rate which is significantly different from the other four variants. U. intestinalis has the highest rate of carbon sequestration rate based on maximum values which range about 1396.68-899.18 ton C/m^2/year in Nuniarchara in longline method [63].

Carbon sequestration rate has a direct correlation with internal factors of seaweed, including pigment content and growth rate [64-68]. Whereas, the growth rate is influenced by seaweed variants, location and seasonal cultivation periods. Study on 5 different seaweed variants, we observed that *U. intestinalis* has the highest daily growth rate which is significantly different from others [69-71].

The different capability of seaweeds on carbon sequestration rate was also indicated in different cultivation periods. The statistical analysis result showed a significantly different carbon sequestration rate ($P<0.05$) among three cultivation periods during this study [72-75]. The second cultivation period indicated a higher rate of carbon sequestration than the other two periods. Seaweeds cultivation which is held during different seasonal cultivation periods would be influenced by temporal variabilities of environmental factors [76]. Seaweeds are exposed to seasonal variations of abiotic factors that influence their metabolic responses, including photosynthetic growth rate [77-80]. Seaweeds absorb CO_2 from waters through the photosynthesis process then transformed it into a carbohydrate compound. Good environmental conditions would give higher opportunities to absorb more CO_2 from the environment. The higher the CO_2 absorbed seaweed, the more productive seaweeds are cultivated [81].

Trends of carbon sequestration rate were influenced by different seaweed variants. Generally, *U. intestinalis* has a higher sequestration rate than the other four seaweed variants. Analysis of variance showed a significant difference ($P<0.05$) in the trend of carbon sequestration among seaweed variants [82]. *U. intestinalis* showed a higher carbon sequestration rate than other species which were cultured in Cox's Bazar coast in the longline and net method [83].

The trend of carbon sequestration was also different between cultivation periods. Every species showed the most carbon sequestration in the Pre-monsoon period and less carbon sequestration in the winter period [84]. But, between the two methods, longline method showed much carbon sequestration than the net method both in the two stations [85]. Statistical analysis caused a significant difference ($P<0.05$) in the trend of carbon sequestration between cultivation periods [86]. The second and third periods showed a higher carbon sequestration rate than the first period. The second and third periods were categorized as the productive period for seaweed cultivation, but the first was non-productive. This could be indicated that seaweed's capability on carbon sequestration rate is correlated to cultivation productivity [87].

Generally, *U. lactuca* and *Polysiphonia sp.* showed the decreasing trend of carbon sequestration patterns during cultivation. It was at a high rate at the beginning (day 15) then decrease at the end of the cultivation (day 45) on every cultivation period [88]. ANOVA indicated significant differences ($P<0.05$) of carbon sequestration pattern between seaweed ages at day-15, 30, and 45 of culture [89].

Seaweed cultivation can positively contribute to reducing CO_2 from the atmosphere regarding the role of the ocean ecosystem in the blue carbon context. The development of seaweeds aquaculture not only can increase national production but also enhance the economic level of coastal people and improve environmental conditions through its carbon sequestration capability [90-92]. It is interesting to note that 3.5 tons of algae production utilizes 1.27 tons of carbon about 0.22 tons of nitrogen and 0.03 tons of Phosphorus. Carbon sequestration capability positively correlated with seaweed aquaculture productivity. The main aspect that is very important in influencing seaweed aquaculture productivity is the seasonal cultivation period. Moreover, the seasonal aspect will differentiate physical and chemical conditions of water quality parameters, the physical and chemical factors affecting the growth of these plants [93]. The quantity of seaweed production is in line with carbon sequestration volume by seaweed aquaculture. Another important aspect is the selection of seaweed species/variants which are suitable for different specific locations with different environmental conditions [94]. Evaluation of seaweed growth is very important for species suitability selection based on location and planting period. The age of seaweed also influences its performance during the cultivation process.

U. intestinalis and *Gracilaria tenuistipitata* showed the highest daily growth rate at the beginning of cultivation [95]. Much consideration is needed to arrange a strategy for developing seaweeds aquaculture in order to make this activity become efficient both economically and environmentally. Implementation strategy for climate change mitigation has to consider at least these three important aspects on seaweeds aquaculture development scheme [96]. Seasonal cultivation periods will be different between different areas; different seaweed variants could not always be suitable in any different cultivation areas and different ages of seaweed will be different on carbon sequestration rate [97]. Bangladesh has great potential areas to develop seaweed aquaculture activity for coastal people's economic enhancement. Optimal utilization of the potential area for seaweed aquaculture could reduce a great quantity of CO_2 from the atmosphere and help to mitigate the global climate change process [98]. Planning and implementation processes of policy and management of coastal carbon ecosystems for climate change mitigation require that stakeholders and community engaged in both climate change mitigation and coastal activities [99]. Therefore, the government should play a significant role in managing and regulating a way to combine seaweed aquaculture activity as one of coastal community livelihood with awareness of people to do this activity not only for economic interests but also for environmental concern.

Conclusion

Seaweed capability on carbon sequestration could be influenced by seaweeds variants, cultivation periods and seaweed age (day of culture). *U. intestinalis* had the highest carbon sequestration rate and *Polysiphonia sp.* had the lowest. Seasonal cultivation periods have also influenced the capabilities of seaweed on carbon sequestration. These were caused by variabilities conditions of environmental factors between different cultivation periods. The implementation strategy for climate change mitigation has to consider at least three important aspects of the seaweeds aquaculture development scheme. Seasonal cultivation periods will be different in any area; different seaweed variants could not always grow well in any different cultivation area and different ages of seaweed would have different capabilities on carbon sequestration.

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