Experimental Cultivation of Seaweed on the Cox's Bazar Coast Bangladesh

BANGLADESH MARINE FISHERIES ASSOCIATION

Experimental Cultivation of Seaweed on the Cox's Bazar Coast, Bangladesh

Bangladesh Marine Fisheries Association

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Honorable Prime Minister Sheikh Hasina at Cox's Bazar Sea Beach

Tapan Kanti Ghosh
Senior Secretary
Ministry of Commerce
Government of the People's Republic of Bangladesh

Message

Seaweed cultivation is a prominent sector in Asia. It's a piece of great news that the Bangladesh Marine Fisheries Association (BMFA) is going to publish the seaweed report by their project of "Experimental Cultivation of Seaweed on the Cox's Bazar Coast, Bangladesh" that we have funded last year.

Bangabandhu Sheikh Mujibur Rahman, the nation's founding father, had a vision of a thriving and developed "Sonar Bangla," and to carry out Bangabandhu's wish, Honorable Prime Minister Sheikh Hasina announced the country's strategic plan, "Vision 2041," emphasizing the Blue Economy for further economic progression.

For the most effective use of marine resources as well as for sustainable economic and social development, the blue economy is crucial. The ocean provides humans with the food and energy they require. The Bangladeshi government has taken steps to ensure the sustainable use of maritime resources to achieve overall development.

Seaweed is an important component of the Blue Economy. It can change the economic structure once it is established. We are trying to promote seaweed cultivation research. This research project was successful and we are planning to extend this project next year.

Joy Bangla
Joy Bangabandhu

Tapan Kanti Ghosh

Sayeed Mahmood Belal Haider
Director General (Additional Secretary)
Bangladesh Oceanographic Research Institute
Ministry of Science and Technology

Preface

An incredibly useful marine commodity and a potential blue economy prospect is seaweed. Seaweed extract is utilized in the pharmaceutical, medicinal, food, and cosmetics industries, among others. It is referred to as the "new superfood" since it contains many essential vitamins that our bodies require, antioxidants, and seaweed, which strengthens our immune systems. Making fish food using it is also advantageous. Since Japan, China, and Korea are the countries that produce and consume the most seaweed, people tend to associate it with Asia. Nevertheless, seaweed can be found all around the earth. Many goods that we consume daily, whether deliberately or unknowingly, include seaweed. Restaurants also use seaweed. Seaweed is one of the most essential ingredients in sushi, which is one of the most adored and well-liked foods in today's society.

Natural seaweed growth occurs in the hard substratum like rocks, plants, shells and discarded fishing nets. In Bangladesh, there are over 215 species of seaweed belonging to 102 groups. Seaweeds are typically found from October to April but are most abundant from December to March due to seasonal variations in water quality characteristics. In 1670, seaweed was first grown in the Tokyo Sea. Two times a month, seaweed can be gathered from cultures that can last for around six months a year. Seaweed can be cultured since it has a high market value, which will help the blue economy expand.

Bangladesh Oceanographic Research Institute (BORI) is working on seaweed taxonomy, culture, and extraction of valuable chemicals like agar, carrageenan, and alginate since 2018. BORI got very positive findings and continues its research. BORI is now providing technological help to different government and non-government organizations. We provided technical support to Bangladesh Marine Fisheries Association (BMFA) for a successful “Experimental Cultivation of Seaweed on the Cox’s Bazar Coast, Bangladesh”. We got good seaweed production and it was quite a successful project.

BORI is working on the different sectors of the ocean to meet the dream of a Blue Economy. Continuous efforts are making to harness the ocean resources..

Sayeed Mahmood Belal Haider

Nurul Qayyum Khan
President
Bangladesh Marine Fisheries Association

Preface

The Coastal and Marine environments of Bangladesh are home to diverse habitats including mangroves, muddy and sandy tidal flats, seaweed beds, sub-tidal rocky reef with corals, estuaries, pelagic waters and seabed that support a rich marine biodiversity.

I am happy to know that Bangladesh Marine Fisheries Association (BMFA) is going to publish a report on seaweed cultivation research by their project “Experimental Cultivation of Seaweed on the Cox’s Bazar Coast, Bangladesh” that we conducted with the help of Business Promotion Council (BPC), Ministry of Commerce, and Bangladesh Oceanographic Research Institute (BORI). This report encompasses the cultivation techniques, challenges in cultivation, nutritional status, pollution status, and recommendation for future research.

The delineated maritime limit in the Bay of Bengal is blessed with valuable living and non-living marine resources for Bangladesh. Bangladesh's territorial sea measures 12 nautical miles, its exclusive economic zone (EEZ) measures 200 nautical miles, and its continental shelf measures 354 nautical miles. In the Bay of Bengal, our coastline stretches over 710 kilometers. Coastal aquaculture, local and international maritime tourism and other marine-related industries play a significant part in Bangladesh's overall socioeconomic development.

BMFA is catching marine fish from the Bay of Bengal for a long time. Fish resources are being declined and it's time to explore new sectors. That’s why we implemented a pilot project on seaweed. It has a huge potential in Bangladesh and it is being cultivated worldwide.

The authors of report would like to express their sincere gratitude to the BMFA, & BORI for technical support in the field and laboratory studies and BPC for financial support.

Experimental seaweed cultivation by Bangladesh Marine Fisheries Association as part of Blue Economy program of the Government and its results will make businessmen interested for investing.

Nurul Qayyum Khan

Bangladesh Marine Fisheries Association

Experimental Cultivation of Seaweed on the Cox's Bazar Coast, Bangladesh

Abstract

The current research was carried out in Rezu Khal to determine the best location for seaweed cultivation. This research also discovers commercially valuable seaweed species that are appropriate for production. Temperature, salinity, pH, DO, conductivity, and FNU of surface water ranged from 20.9-26.2°C, 24-26.2‰, 6.45-8.5, 92-105%, 33256-64267 µS/cm, 11.1-42.8, respectively. Phosphate-phosphorus (PO_4-P) concentrations in surface water were 2.6-7.6 mg/l, 0.04-0.12 mg/l for Nitrate-nitrogen (NO_3-N), 0.002-0.04 mg/l for Nitrite-nitrogen (NO_2-N), 0.15-0.83 mg/l for Silica (SiO_3), and 0.13-0.28 mg/l for Ammonia (NH_4). In the chosen areas, three seaweed species (*Gracillaria lemaneiformis*, *Hypnea musciformes*, and *Sargassum oligocystum*) were cultured. For the culture, two methods (net and long line) were used. Every 15 days, 15-20 kg *G. lemaneiformis* was identified in the net method in the current investigation. Every 15 days, *H. musciformes* grew between 4 and 12 kg. *S. oligocystum* grew well, however it was difficult to keep it alive. The average value of ash, moisture, protein, lipid, carbohydrate, and fiber were ranged between 13.55-13.58%, 23.89-24.04%, 12.94-13.11%, 0.96-0.97%, 43.19-43.32%, and 5.04-5.32% *G. lemaneiformis* and *H. musciformes*. The concentration of Ca, Mg, Cu, Fe, Mn, Zn, Ni, Pb and Cr varied between 767.14-798.14, 8249-8663, 10.15-10.59, 6038.57-7566.29, 9.71-9.93, 29.3-29.54, 11.68-11.77, 3.56-3.91 and 0.40-0.59 mg/kg in both seaweed (*G. lemaneiformis* and *H. musciformes*). Seaweed cultivation along those areas has provided a new dimension to the promise and possibilities of seaweed mariculture on the Bangladesh coast. The findings of this study imply that seaweed growing is viable, and coastal residents can engage in seasonal income-generating activities in coastal waters.

Keywords: Biochemical, Seaweeds, Physico-chemical parameters, Taxonomic identification, St. Martin's Island

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Introduction

Introduction

Seaweed is a multicellular macroscopic sea alga with no actual roots, stems, flowers, or leaves that is essential to the aquatic environment (Bhuyan et al. 2022; Bhuyan et al. 2021; Salehi et al. 2019; Aasim et al. 2018). Tropical, subtropical, and temperate regions have the greatest abundance of seaweeds (Barrientos et al. 2021). They grow on rocks, coral, shells, sand, mud, and other plant bodies (Nedumaran, 2017). They usually reside attached to rock or other hard substrata below the high-water mark, up to a depth of 118 m, in oceans, rivers, lakes, and other bodies of water when 0.1% photosynthetic light is available (Pereira, 2015; Maberly, 2014). Based on their natural coloring or pigmentation, they are typically classified as red (Rhodophyceae), brown (Phaeophyceae), or green (Chlorophyceae) seaweeds (Yalçn et al. 2021; Rashad and El-Chaghaby, 2020).

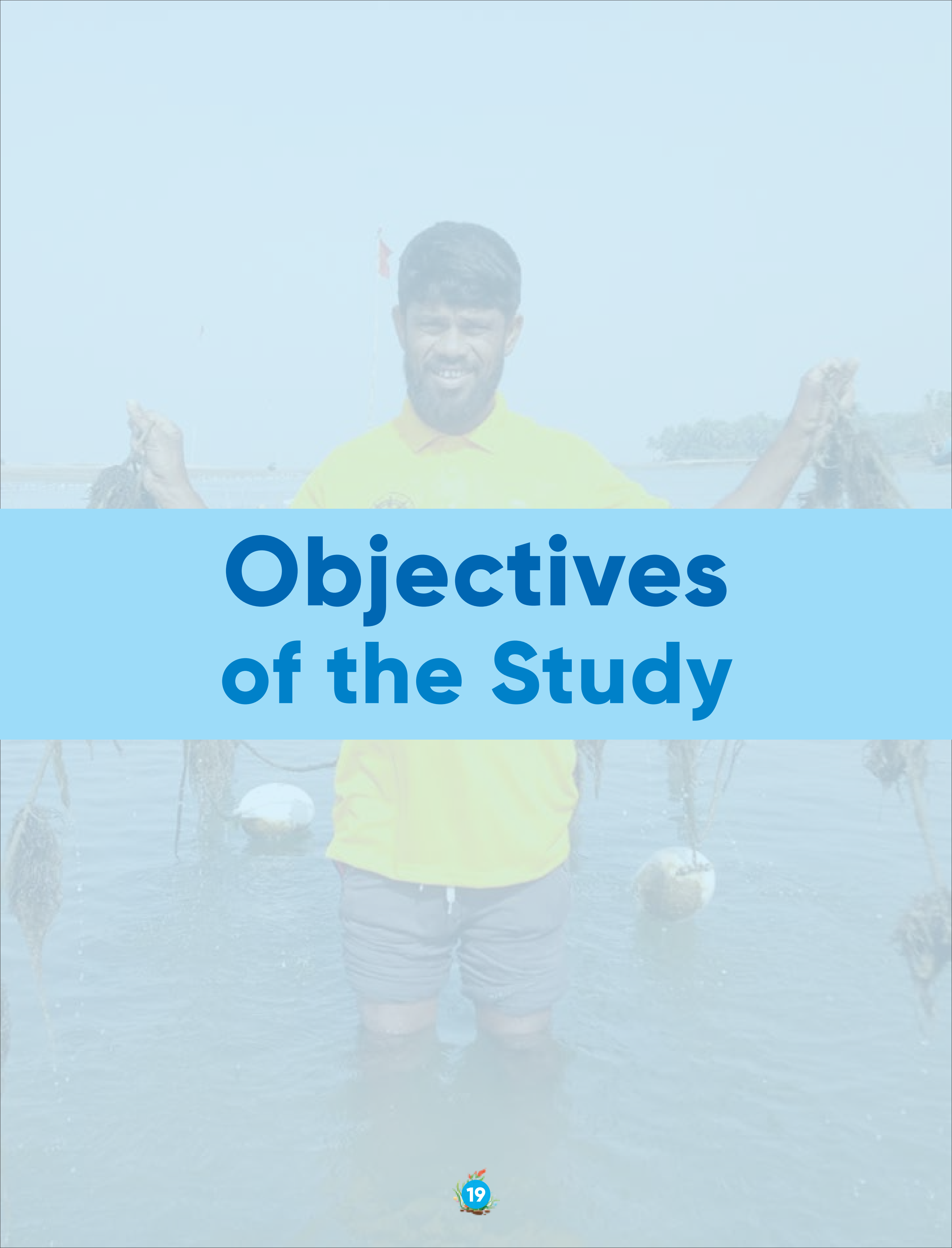
Seaweed is a versatile raw material used in the production of cosmetics, fertilizers, and the extraction of industrial gums and chemicals used in the culinary, and pharmaceutical industries (Pradhan et al. 2022; Gomez-Zavaglia et al. 2019; Pati et al. 2016). For a long time, seaweed has been a staple diet in many other countries. Green seaweeds such *Enteromorpha* sp., *Ulva* sp., *Caulerpa* sp., and *Codium* sp. are used solely as food sources (Pérez-Lloréns, 2019; Dhargalkar, 2015). These are frequently served as fresh salads or as cooked veggies with rice (Shafiuddin, 2019). Fish curry and beef meals, as well as soups and accompaniments, are made using *Porphyra* (Nori), *Laminaria* (Kombu), and *Undaria* (Wakame) (Khan and Satam, 2003). Apart from that, seaweed is used in commercially produced burgers, juices, sandwiches, chocolate, ice cream, cakes, salads, biscuits, and chips (Sarkar et al. 2016).

From 1995 to 2012, global seaweed aquaculture production more than tripled, reaching 23.8 million tons per year, with China and Indonesia accounting for 81% of global production (Kotta et al. 2021; FAO 2014). Due to environmental concerns, seaweed production in Europe is entirely relied on natural stock collection, and it has decreased by about a third from 2000 to 2012, to around 230,000 tons per year (Thomas et al. 2019). In the coming years, cultivation is likely to play a significant role in addressing the rising gap between supply and demand. As research programs and businesses establish capacity for seaweed biomass cultivation and processing, seaweed production has recently gained traction (Ligtvoet et al. 2019; Sandquist et al. 2017). Many economic, political, and logistical challenges remain to be overcome, many of which are region-specific, not least of which is identifying suitable areas of shoreline that could host effective cultivations without interfering with current maritime operations (Prutzer, 2019; Jackson, 2018).

Seaweed grows from November to March in Bangladesh, depending on turbidity, salinity, and temperature (Sarker et al. 2021; Aziz and Alfasane, 2020). By familiarizing poor farmers with cost-effective technologies, seaweed culture can be introduced in places appropriate for its development (Siddiqui et al. 2019). Seaweeds can be grown utilizing natural materials like bamboo and rope (Bokhtiar et al. 2022; Islam et al. 2021). Seaweed culture can be a good sector for coastal villages in Bangladesh because it involves little input, yields high returns, and employs a large number of people. From Cox's Bazar to the Sundarbans, excellent locations for seaweed cultivation exist (Hossain et al. 2021; Siddiqui et al. 2019).

Seaweed can provide nutrients that is required for body growth. Additionally, it might be a lucrative source of foreign income. Along with harvesting sea seafood, cultivating seaweed can provide an alternate source of income. It can be a lucrative sector, especially for women (Makame and Shackleton, 2021; Shafiuddin, 2019; Msuya and Hurtado, 2017). It is possible to build a massive industry with endless potential. If industrial entrepreneurs from similar disciplines join forces with the government, they may be able to open the door to a new world in the blue economy, enriching the national economy. Increasing the production of non-traditional marine resources requires the employment of contemporary technology (Siddiqui et al. 2019).

Natural abundance of seaweed has been documented in Bangladesh's south-eastern region, and natural seaweed growth on the St. Martin's Island is massive (Islam et al. 2021; Islam et al. 2020; Bhattacharjee and Islam, 2014). Within the coastal areas of Bangladesh, there are 138 seaweed species, 18 of which are commercially important, and 55 genera (BFRI, 2019). Experiential seaweed cultivation is practical research aimed at developing a sustainable and profitable seaweed growing method. The goal of this research was to find ideal locations for the cultivation of commercially important seaweed species.



Objectives of the Study

Objectives of the Study

Experiential seaweed cultivation is applied research that aim to develop sustainable and profitable culture technology of seaweed cultivation.

- Find out the suitable sites for seaweed culture.
- To identify commercially culturable seaweed sp.
- To detect the factors that regulate seaweed growth.

Materials and Methods

Materials and Methods

Field Survey

Field survey was carried out from July 2021-October 2021 to identify the suitable site for seaweed culture. Different parameters (e.g., Temperature, salinity, DO etc.) were tested to find out suitable locations. St. Martin's Island also visited frequently for collection of targeted seaweed species since it's a natural habitat of seaweed.

Study Area

After feasibility study, Rezu Khal along the Cox's Bazar coast was selected for culture. This culture area was very close to coast where salinity remain 23-30 ppt.

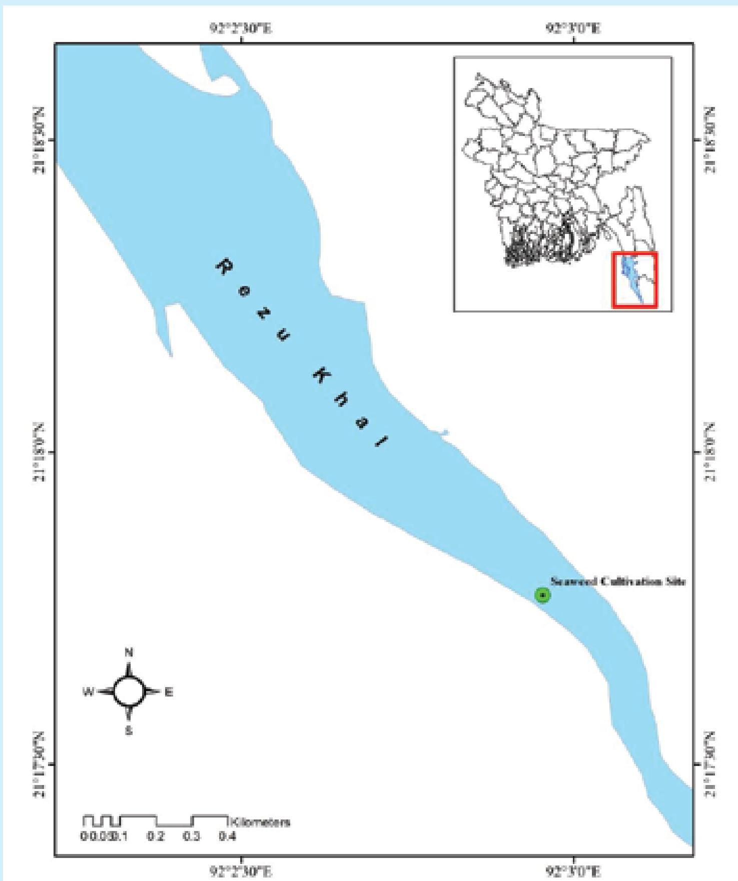


Figure 1. Map showing the seaweed culture site in Rezu Khal, Cox's Bazar.

Geological Information

The cultural site is close to the coast. As a result, saline water enters the Khal. Near the places, there are several mangrove trees. Mermaid Resort, in the east, dumps waste into the Khal every day. A Tilapia Hatchery (Niribili Tilapia Hatchery) in the west regularly discharges eutrophicated or chemically mixed water into the Khal. In the culture site, the soil is largely sandy, but Khal bank is mostly muddy. As a result, the rate of sedimentation is significant and the water transparency is low. During both high and low tides, the water movement is strong.

Selected Seaweed Species for Culture

Three (3) different seaweed species were selected for culture. *Gracillaria lemaneiformis* and *Hypnea musciformes* are known as red seaweed that have huge economic value. *Sargassum oligocystum*, which is a brown seaweed, was another cultivated seaweed. These species are extremely valuable in terms of economics. These species can be used to make agar and carrageenan.

Figure 2. *Gracillaria lemaneiformis*

Figure 3. *Hypnea musciformes*

Figure 4. *Sargassum oligocystum*

Experimental Setup

During the month of November, infrastructure was built. The planting was completed in December. Bamboo was obtained from local residents. Ropes, knives, and other items were acquired from a local market. Bamboo was cut and prepared for seaweed cultivation. The experimental plots were identified using identification leaflets. These identification plates helped to identify the plot. A signboard was erected with project information. The experimental setup is detailed below.

Culture Methods

Two culture method (e.g., net and long line) was applied for the culture. *Gracillaria lemaneiformis* seed was planted both in net and long line method. For net, 5 experiment plots (5m x 5m) were established for culture. 20 m long 5 ropes was used for long line culture (5x2 rope in two plots). *Hypnea musciformes* and *Sargassum oligocystum* was planted in net (4m x 4m). Two experimental plots were set for each species. Coir rope, jute rope and bamboo mats were used as culture materials. For net method, net was fixed with bamboo pillar in four corner and another 4-bamboo pillar in middle of each side. This extra pillar was used so that net can withstand during strong current. Another bamboo pillar used in the middle of the net to make strong structure. Rope was used to tighten the net with bamboo pillar. In long line method, two bamboo pillars were used in each corner of the rope. Here also used extra bamboo pillar in middle of the rope.

Figure 5. *Net Method*

Figure 6. *Net Method*

Physico-chemical Parameters of Water and Sediment

Water parameters like Temperature, pH, Conductivity, Formazin Nephelometric Unit (FNU) were analyzed using Multiparameter (YSI Pro DSS, Made in USA).

Figure 7. Multiparameter (YSI Pro DSS, Made in USA).

Sediment temperature was determined using Thermometer and soil pH was detected using Soil pH Tester (Takemura electric works ltd., Japan).

Figure 8. Soil pH Tester (Takemura electric works ltd., Japan).

Nutrient Analysis (Water)

Nutrients were assessed using colorimeter (Nutrient Auto Analyzer, HACH, DR 900).

Figure 9. Colorimeter (HACH, DR 900).

The USEPA-approved Ascorbic Acid Method was used to assess PO_4-P. (Rand et al. 1976). The Cadmium Reduction Method was used to analyze NO_3-N (Nichela et al. 2014). The ferrous sulfate method was used to determine NO_2-N (Stone et al. 2013; Varner et al. 1953). The USEPA-approved Nessler Method was used to analyze NH_3-N (Mohammad et al. 2004; Varner et al. 1953). The Silicomolybdate technique was used to examine SiO_3 (Parsons, 2013).

Proximate Analysis of Seaweed

Ash determination

The AOAC (2000) method was used to determine the ash content. The ash content was calculated using the residue from the crude lipid determination.

Moisture determination

At 25°C, one gram of powdered sample was placed on the tray of an automatic moisture determination machine, Model Chyo, IB-30, for 10-15 minutes, and the moisture content was measured.

Protein determination

The Micro-Kjeldahl technique was used to determine the protein content (Guebel et al. 1991). Heat for 6 hours a powdered 0.5g sample in 10 ml concentrated H_2SO_4 and 1:1 g digestion mixture (sodium sulphate and mercuric oxide). It was diluted in distilled water up to 100 mL, 10 mL of which was transferred to a micro-Kjeldahl distillation unit and distilled for 10 minutes. The distillate was titrated with 0.02 NHCl after being collected in excess of 2% boric acid solutions with indicator. It was compared to a blank digestion of the same type.

Lipid determination

Lipid content of seaweed was determined by following Mehlenbacher (1960). Powdered 10 g sample was mixed with 150 ml n-Hexane and petroleum benzine solvents at 90:60 ratio. Lipid was extracted using Soxlet apparatus. Powdered 10 g extract was kept in the extraction thimble for eight hours and weighed again. Deference in the weight represented lipid content.

Carbohydrate determination

The percentage of total carbohydrate content was calculated using the following formula: [Percentage of total carbohydrate content = 100– (moisture+protein +lipid+ minerals)].

Fiber determination

Fiber content was determined using the AOAC (2000) method. 200 ml of 0.255 N H_2SO_4 was added to the moisture and fat free 5.0 g sample and heated for 30 minutes before adding 200 ml of 0.313 N (1.25 percent) NaOH solution and boiling for another 30 minutes. The filtrate was weighed after drying at room temperature. The sample was then placed in a muffle furnace for 2-3 hours at 650 degrees Celsius, cooled, and weighed again. The weight difference shows the amount of fiber.

Heavy Metal Determination in Seaweed

The heavy metal contents were determined by AAS using standard analytical procedure (Bhuyan et al. 2019). Sample collection is important stage for metal analysis. Samples were generally carefully handled to avoid contamination. Glassware was properly cleaned, and the reagents were of analytical grade. Distilled water was used throughout the study. Reagents blank determinations were used to correct the instrument readings (Bhuyan et al. 2019). The techniques for samples preparation, standard preparation and analysis for metal analyses have been briefly described below.

Seaweed Sample Preparation

This procedure was also used for destruction of organic matter. Precaution was to be taken to avoid losses by volatilization of elements. The samples were weighed accurately a suitable quantity (10 to 20 g) in a tared silica dish. After that the samples were dried at 120°C in a laboratory oven (Bhuyan et al. 2019). These dishes were then placed in the muffle furnace at ambient temperature and slowly raised temperature to 450°C at a rate of no more than 50°C/h. The samples were ignited in a Muffle furnace at 450°C for at least 8 hrs. After the samples cool, then the dishes were removed from furnace. Then the seaweed samples were digested in desired amount of 50% nitric acid on hot plate. Then the samples were filtrated into a 100 ml volumetric flask using Whatman No. 44 filter paper and washed the residue. Each sample solution was made up to the mark with distilled water (Bhuyan et al. 2019).

Analysis of Sample

The atomic absorption instrument was set up and flame condition and absorbance were optimized for the analyte. Then blanks (deionized water), standards, sample blank and samples were aspirated into the flame in AAS (Model- iCE 3300, Thermo Scientific, Designed in UK, Made by China). The calibration curves obtained for concentration vs. absorbance. Data were statistically analyzed using fitting of straight line by least square method. A blank reading was also taken and necessary corrections were made during the calculation of concentration of various elements (Bhuyan et al. 2019).

Results and Discussion

Results and Discussion

Seaweeds are a source of bioactive substances that have nutritional and biological purposes in addition to being a source of food, feed, and medicine (Lomartire et al. 2021; Yu-Qing et al. 2016). Seaweed cultivation has been increasingly popular in recent years all around the world. For Bangladesh's food, cosmetics, medicines, and fertilizer values in local and worldwide markets, seaweed cultivation has immense promise (Shaika et al. 2022; Aktar et al. 2020).

Growth of Seaweed

Hypnea musciformis

The high production of seaweed found in this study could be attributable to favorable water factors at the culture site. According to physico-chemical criteria of seaweed farming, the Cox's Bazar coast is favorable for seaweed production, according to Islam et al. (2021). *H. musciformis* can withstand a wide variety of temperatures, salinity, and light intensity (Dawes et al. 1976). In the Cox's Bazar coast, Islam et al. (2021) found that the biomass yield from *H. musciformis* (30.23±0.40 kg fw m^{-1}) was much higher than *E. intestinalis* (24.50±0.08 kg fwm-1) and *P. tetrastromatica* (10.18±0.45 kg fw m^{-1}). In St. Martin's Island, Islam et al. (2017) found that the daily growth rate of *Hypnea* sp. was (3.21 ± 0.01% day^{-1}) which is much higher than Inani (0.41 ± 0.06% day^{-1}).

Hoq et al. (2016) discovered a maximum daily growth rate of 3.21±0.01%/day on the 60th day from the St. Martin's Island and a minimum daily growth rate of 0.41±0.11%/day on the 15th day from Inani. St. Martin's Island produced much more biomass of *Hypnea* sp. (11.05±0.10 kg fresh wt./m^2) than Bakkhali and Inani. Bakkhali and Inani may be appropriate places for seaweed cultivation, adding a new dimension to Bangladesh's mariculture prospects (Hoq et al. 2016). At a 60-day culture period, Zafar (2007) used two types of culture systems and discovered growth rates of 1.06 cm/day and 0.95 cm/day for *Hypnea* sp. in St. Martin's Island.

After 25 days of growth with *H. musciformis* on long line ropes in the lagoon of Krusadai Island, India, obtained a four-fold rise in biomass, which is consistent with the findings of Rao and Subbaramaiah (1986). In St. Martin's Island, growth rates of 1.06 and 0.95 cm/day were recorded in a 60-day culture of *Hypnea* sp. using net and suspended rope techniques, respectively (Zafar 2007). From July through January, a suitable season for *H. musciformis* cultivation was reported in the Gulf of Mannar, Bay of Bengal coast, India, with a peak between August and September (Reddy et al. 2006). During a 90-day raft culture of *P. boergesenii* with coir rope in the intertidal sea off India's Mandapam coast, 2,440 g (fresh weight) m^{-2} was produced (Ganesan).

Table 1. Growth rate (kg) of *Hypnea musciformes* in net method cultured in Rezu Khal.

Net Method (4/4m)							
Time (Day)	**0^{th}**	**15^{th}**	**30^{th}**	**45^{th}**	**60^{th}**	**75^{th}**	**90^{th}**
Experimental plot	Growth (kg)						
1	4	5	7	10	12	10	11
2	4	6	6	12	12	11	10

H. musciformis produced the lowest biomass production in January (8.0 ± 1.5 g fw m^{-1}) and the largest biomass yield in August (403.0 ± 10.0 g fw m^{-1}) (Ganesan et al. 2006). Enhanced seedling density (30 g fw m^{-1} and above) increased biomass output. The DGR of 10 g fw m^{-1} initial seedling density was higher (7.6-10.9%), and it differed substantially from the DGR of the other seedling densities (Ganesan et al. 2006). Summer and autumn were the peak seasons for *H. musciformis* development along the Moroccan Atlantic coast. The species remained productive virtually all year, with the highest levels (52-77%) in October and the lowest levels (0-2%) in April and June in 1997 and February and April (3-10%) in 1998 (Aziza et al. 2008).

The red alga *H. musciformis* dry weight levels in Florida's Atlantic and Gulf of Mexico coastal sites were lowest in late winter and early spring, increased throughout the summer, and peaked in the fall (Durako and Dawes, 1980). In July and November, *H. musciformis* reached two doublings per day maxima of 0.12 and 0.09, respectively. In July, *H. cornutu* reached a maximum S.G.R. of 0.19 doublings per day, the most ever recorded (Friedlander and Zelikovitch, 1984).

Gracillaria lemaneiformis

Gracilaria tenuistipitata is an essential seaweed species that is adaptable to a variety of conditions and is a valuable raw material for agar manufacturing (Yarnpakdee et al. 2015). *Gracilaria* can withstand a wide range of environmental conditions (Abreu et al. 2011; Raikar et al. 2001). The ideal atmosphere could boost the rate of growth of seaweeds by improving the nutrient absorption mechanism (Hoq et al. 2016). Another element that has been discovered to influence seaweed farming production is harvesting duration. Harvesting crops on time provides great crop quality and market value. Temperature, salinity, and light all have an impact on *Gracilaria* sp. growth and spread (Raikar et al. 2001). Seaweed sp. was largely grown in calm seas, preferably in the lagoons of India's Gulf of Mannar (Reddy et al. 2006). Salinity, temperature, transparency, pH, and DO were found to be suitable for *Gracilaria tenuistipitata* cultivation in the Cox's Bazar coast by Bokhtiar et al. (2022).

Table 2. Growth rate (kg) of *Gracillaria lemaneiformis* in net method cultured in Rezu Khal.

Net Method (5x5m)							
Time (Day)	**0th**	**15th**	**30th**	**45th**	**60th**	**75th**	**90th**
Experimental plot	Growth (kg)						
1	7	18	20	20	20	15	16
2	7	15	20	20	19	16	15
3	7	15	19	20	18	15	15
4	7	16	18	19	16	16	15
5	7	16	19	20	18	15	15

Table 3. Growth rate (kg) of *Gracillaria lemaneiformis* in long line method cultured in Rezu Khal.

Long line Method (10m/5 rope)							
Time (Day)	**0th**	**15th**	**30th**	**45th**	**60th**	**75th**	**90th**
Experimental plot	Growth (kg)						
1	5	8	10	12	12	7	8
2	5	7	9	12	13	4	5

Sargassum oligocystum

Sargassum oligocystum is a dominating species in the marine ecology, playing an important ecological role. *Sargassum* has more essential and non-essential amino acids, essential fatty acids, and minerals than kelp (Redmond et al. 2014). *Sargassum* also includes phycocolloids, bioactive chemicals, and polyphenols, all of which could be used in nutraceuticals and medicine (Gupta and Abu-Ghannam 2011; Namvar et al. 2013). Holdfast regeneration of the cut fronds allows for several harvests, allowing a seeded line to produce for two to four years. The first year's harvest occurs between December and January, whereas the second year's harvest occurs between October and January (Redmond et al. 2014).

In all stages of cultivation, biofouling and predatory organisms can cause problems. Other algae and invertebrates can adhere to the *Sargassum* and the culture lines, vying for space and resources (Redmond et al. 2014). *Sargassum* sp. peaks between November and April, when ocean temperatures are at their lowest (22-25°C). The temperature of 24°C was shown to be around the optimal for the development of *Sargassum* embryos in culture tests. The timing of these different life history events is thought to be synchronized for maximal reproduction and resettlement, as well as providing ideal conditions for embryo growth (De Wreede, 1976). In the present study, there was challenge of survival. It survives and growth was good. There is huge potential of this species culture commercially.

Effects of Physico-chemical Parameters on Seaweed Growth

There are external and internal variables in seaweed cultivation that have a significant impact on the growth rate of the seaweed (Gultom et al. 2019). Water quality is one of these crucial variables. On seaweed cultivation, optimal water quality factors are critical (Rusdi et al. 2017; Warnadi et al. 2017). Dissolved oxygen levels and water temperature changes have a substantial impact on the productivity rate of ecological seaweed growing. Temperature and dissolved oxygen fluctuations induced by weather conditions or other natural factors have a positive link with *Eucheuma cottonii* seaweed cultivation rate and productivity (Rahman et al. 2019).

Table 4. Water quality criteria for seaweed cultivation (Source: Zafar, 2005, 2007).

Parameters	Unsuitable	Suitable	Strongly suitable
Depth (m)	<2 or >15	1-2	2-15
Wave (cm)	0.10->0.40	0.10-<0.20	0.20-0.30
Water Transparency (cm)	<30	30-100	>100
Salinity (ppt)	<4 or >37	24-37	28-34
Water Temperature (°C)	<20 or >30	20-24	24-2 S
pH	<6.5 or>8.5	6.5-<7.5	7.5-8.5
DO (mg/l)	<4 or >7	6.1-7	4-6
Alkalinity (ppm)	<45 or >130	80-120	100-130

Rainfall, evaporation, air humidity, air temperature, wind speed, and the intensity of solar radiation all influence the temperature of water on the surface. As a result, seasonal patterns in surface temperatures are common (Morain, 1999). The water temperature for seaweed cultivation is between 27°C and 30°C, with daily temperature variations of no more than 4°C. Temperature has direct and indirect effects on photosynthesis in the water (Sulistiawati et al. 2019). Temperature has a direct effect on photosynthesis because it regulates enzyme processes. High temperatures can raise the maximum rate of photosynthesis, while modifying the hydrological structure of the water column has an indirect effect on phytoplankton distribution (Carey et al. 2012).

Table 5. Physico-chemical parameter in the seaweed culture site on Day 0 (01.12.2021).

Parameters	High tide	Low tide
Temperature (˚C)	26	26
Salinity (‰)	25	26
pH	7.95	8.0
DO (%)	92	94
Conductivity (µS/cm)	41188	33344
FNU	11.1	15.7
Phosphate-phosphorus (PO_4-P) (mg/l)	7.6	5.68
Nitrate-nitrogen (NO_3-N) (mg/l)	0.05	0.04
Nitrite-nitrogen (NO_2-N) (mg/l)	0.012	0.005
Silicate (SiO_3) (mg/l)	0.33	1.40
Ammonia (NH_3) (mg/l)	0.26	0.25 (150 ml)

Although the effect varies from species to species, temperature is a promising environmental component that controls the growth rate of seaweeds. The color of seaweed is said to turn pale and harmful when the water temperature is too high (Burdames and Ngangi, 2014). In Nuniachara, Cox's Bazar sadar, Bokhtiar et al. (2022) recorded 22°C. Uddin (2019) measured temperatures ranging from 24.0 to 31.5°C at Salimpur coast algae farming site. Temperatures of 28-31°C were reported by Rahman et al. (2019) at an Indonesian *Eucheuma cottonii* cultivation site. In seaweed culture sites in Sulawesi Province, Indonesia, Sulistiawati et al. (2019) found an average temperature of 30.5°C. Islam et al. (2017) recorded 23.8°C to 25.6°C at St. Martin's Island, 21.7 to 24.1°C in Bakkhali, and 22.1°C to 25.5°C in Inani. Because of the ideal temperature range, *Hypnea* sp. grew well on the St. Martin's Island (Islam et al. 2017). In St. Martin's Island, Bakkhali, and Inani, Hoq et al. (2016) measured 23-25°C, 25-28°C, and 23-25°C, respectively. Guist et al. (1982) discovered that keeping the water temperature at 18-24°C boosted the biomass of *H. musciformis* by 20%. Ding et al. (2013) discovered that *Hypnea* grows rapidly at temperatures between 15 and 25°C.

Temperatures varied from 20.9-26.2°C, which is ideal for culture of the seaweed species *G. arcuata* and *G. taxtorii* from Japan, which grow best at 20°C. *G. venniculophylla*, *G. incwvata*, *G. foliifera*, *G. corticata* from Japan and *G. foliifera*, *G. corticata* from India had optimum growth rates at 25°C, while *G. edulis* from India and *G. lichenoides* from Malaysia have optimum growth rates at 30°C. Only *G. venniculophylla* was found to have a high temperature tolerance limit of up to 35°C (Raikar et al. 2001). When the water temperature was between 18° and 24°C, and there was continuous water flow, additional nitrogen, and phosphate, the maximum growth rates were found (Guist et al. 1982).

Table 6. Physico-chemical parameter in the seaweed culture site on Day 15 (15.12.2021).

Parameters	High tide	Low tide
Temperature (˚C)	23	21
Salinity (‰)	24	24
pH	7.5	7.6
DO (%)	95	93
Conductivity (µS/cm)	64267	49352
FNU	13.2	16.1
Phosphate-phosphorus (PO_4-P) (mg/l)	2.58	5.12
Nitrate-nitrogen (NO_3-N) (mg/l)	0.09	0.07
Nitrite-nitrogen (NO_2-N) (mg/l)	0.041	0.003
Silicate (SiO_3) (mg/l)	0.26	0.15
Ammonia (NH_3) (mg/l)	0.22	0.13

The salinity of the water is normal at the bottom of the sea, but not at the surface. Because the waters of the research area are combined with freshwater from rivers during the measurement process, the value between the minimum and maximum reveals fairly different results. Salinity plays a crucial influence in the survival of aquatic biota. Salinity levels in sea waters vary with geography and time, with an increase in salinity due to evaporation and sea ice freezing, and a decrease in salinity due to precipitation and freshwater inflow from rivers (Tomascik, 1997). In the cultivation of seaweed, salinity is crucial. Seaweed growth can be affected by a salinity range that is too high or too low. Water circulation, evaporation, rainfall, and river flow all contribute to the variance in salinity achieved in waterways. Seasonal fluctuations in salinity are caused by a variety of variables, one of which is the season. The influence of rainfall in the West season, while the salinity will rise again in the East season (Bricheno et al. 2021).

Table 7. Physico-chemical parameter in the seaweed culture site on Day 30 (30.12.2021).

Parameters	High tide	Low tide
Temperature (˚C)	24	22
Salinity (‰)	25	25
pH	7.7	7.8
DO (%)	98	100
Conductivity (µS/cm)	62345	48453
FNU	14.2	15.1
Phosphate-phosphorus (PO_4-P) (mg/l)	3.60	5.20
Nitrate-nitrogen (NO_3-N) (mg/l)	0.08	0.06
Nitrite-nitrogen (NO_2-N) (mg/l)	0.03	0.002
Silicate (SiO_3) (mg/l)	0.16	0.15
Ammonia (NH_3) (mg/l)	0.13	0.14

Salinity is a significant determinant of osmotic equilibrium; it is a prudent and potential factor for growing seaweeds. According to Burdames and Ngangi (2014), an optimum salinity value for *E. cottonii* seaweed growth is between 28 and 33 gr/L. Seaweed grows best in hypohaline salinity levels in field cultivation trials (Van Ginneken, 2018). In Nuniachara, Cox's Bazar sadar, Bokhtiar et al. (2022) found an average of 32. In an algae growing site on the Salimpur coast, Uddin (2019) found salinity ranging from 6 to 21‰. Rahman et al. (2019) found 30-36 salinity in an Indonesian *E. cottonii* production location. The salinity of the seaweed cultures sites in Sulawesi Province, Indonesia, ranged from 29.22 to 32.33‰ (Sulistiawati et al. 2019). Salinity levels of 31.1 to 32.5‰, 27.1 to 29.9‰, and 29.5 to 30.5‰ were found in St. Martin's Island, Bakkhali, and Inani, respectively (Islam et al. 2017). In St. Martin's Island, Bakkhali, and Inani, Hoq et al. (2016) recorded 31-32‰, 27-29‰, and 29-30‰, respectively. When the salinity went below

24‰, Zafar (2007) detected reduced growth of *Hypnea* sp. from St. Martin's Island, and greater growth when the salinity climbed (>30‰). Summer biomass yield of *H. musciformis* was reduced due to high water salinity along the Florida coast (Durako and Dawes, 1980). In the current study, the salinity in Rezu Khal ranged between 24-26.2‰, and seaweed growth was good in this salinity range. As a result, this study reveals that one of the critical variables for having the best biomass output in Rezu Khal is a consistent and moderate salinity. All *Gracilaria* species had different growth rates as a function of salinity, although most of them reached their maximum growth rates at a standard seawater salinity of 35‰ (Raikar et al. 2001).

Table 8. Physico-chemical parameter in the seaweed culture site on Day 45 (15.01.2022).

Parameters	High tide	Low tide
Temperature (˚C)	21	21
Salinity (‰)	25	24
pH	7.6	7.5
DO (%)	95	96
Conductivity (µS/cm)	45299	39116
FNU	24.03	32.12
Phosphate-phosphorus (PO_4-P) (mg/l)	6.56	4.25
Nitrate-nitrogen (NO_3-N) (mg/l)	0.12	0.09
Nitrite-nitrogen (NO_2-N) (mg/l)	0.03	0.02
Silicate (SiO_3) (mg/l)	0.83	0.27
Ammonia (NH_3) (mg/l)	0.19	0.16

The osmotic equilibrium, which is determined by water salinity, stimulates nutrient accumulation from water, albeit the range of optimum salinity varies by species. Phosphate is an important nutrient for plants and aquatic algae, and it has a significant impact on aquatic productivity. Differences in phosphate concentration are typically induced by differences in measurement time and sampling location. Furthermore, the presence of organic matter in the form of residential waste (detergent), agricultural waste, or water flow erosion of phosphorus rock might be a factor that causes variances in phosphate concentration. According to Effendi (2003), the majority of phosphate comes from land-based organic material such as industrial or home waste (detergents). The total phosphate levels measured throughout the measuring process show that the waters of the study site are still appropriate and optimal for seaweed production, with total phosphate levels of 0.051-0.1 mg/l (Rugebregt et al. 2020).

Table 9. Physico-chemical parameter in the seaweed culture site on Day 60 (30.01.2022).

Parameters	High tide	Low tide
Temperature (˚C)	21	21
Salinity (‰)	26	25
pH	8.25	7.9
DO (%)	99	105
Conductivity (µS/cm)	39245	33256
FNU	39.8	41.08
Phosphate-phosphorus (PO_4-P) (mg/l)	7.28	5.68
Nitrate-nitrogen (NO_3-N) (mg/l)	0.06	0.04
Nitrite-nitrogen (NO_2-N) (mg/l)	0.02	0.01
Silicate (SiO_3) (mg/l)	0.29	0.24
Ammonia (NH_3) (mg/l)	0.28	0.26

Coastal waters with a nitrate value of 0.008 mg/l are ideal for aquaculture (Sulistiawati et al. 2019). This occurs because Station 7 is located near the pond waters, close to the settlements of the locals. High amounts of nitrate can be created by liquid waste from agriculture and plantation activities, as well as input from the soil and adjacent activities (Indriani and Suminarsih, 2003). The existence of communities that allow nitrates to enter the waters causes differences in mean values of the nitrate parameters. For optimal phytoplankton growth in the water, more nitrate nutrients are required than phosphate nutrients. Electric storms, nitrogen-binding organisms, and bacteria that consume ammonia are all potential sources of nitrates. The breakdown of plant or animal wastes causes an increase in ammonia concentration (Effendi, 2003).

Table 10. Physico-chemical parameter in the seaweed culture site on Day 75 (15.02.2022).

Parameters	High tide	Low tide
Temperature (˚C)	23	24
Salinity (‰)	24	23
pH	8.1	7.8
DO (%)	100	101
Conductivity (µS/cm)	38225	34254
FNU	36.8	42.1
Phosphate-phosphorus (PO_4-P) (mg/l)	7.1	5.2
Nitrate-nitrogen (NO_3-N) (mg/l)	0.05	0.03
Nitrite-nitrogen (NO_2-N) (mg/l)	0.01	0.02
Silicate (SiO_3) (mg/l)	0.25	0.21
Ammonia (NH_3) (mg/l)	0.23	0.22

Phosphate and nitrate levels were 0.10 to 0.21 mg/l and 0.22 to 0.44 mg/l on the St. Martin's Island, 0.22 to 0.33 mg/l and 0.74 to 1.1 mg/l in Bakkhali, and 0.19 to 0.26 mg/l and 0.25 to 0.64 mg/l in Inani, according to Islam et al. (2017). 2.6-7.6 mg/l for PO_4-P, 0.04-0.12 mg/l for NO^3-N, and 0.002-0.04 mg/l for NO_2-N were found in the Rezu Khal seaweed culture site in this investigation. In Nuniachara, Cox's Bazar sadar, Bokhtiar et al. (2022) found an average of 0.632 mg/l NO_3-N and 0.443 mg/l NO_2-N. In an algae growth site on the Salimpur coast, Uddin (2019) found 0.56 to 0.69 mg/l NO_3-N, 0.18 to 0.47 mg/l NO_2-N, and 0.90 to 1.10 mg/l PO_4-P. In the surface water of a *Kappaphycus alvarezii* and *Spinosum* sp. cultivation site in Sulawesi Province, Indonesia, Sulistiawati et al. (2019) found 0.008 mg/l to 0.09 mg/l PO_4. In the surface water of a seaweed culture site in Sulawesi Province, Indonesia, nitrate levels ranged from 0.005-0.06 mg/l (Sulistiawati et al. 2019). In St. Martin's Island, Bakkhali, and Inani, Hoq et al. (2016) found 0.73 mg/l, 0.67 mg/l, and 0.51 mg/l NO_3-N, and ND, 0.45 mg/l, and 0.23 mg/l NO_2-N, respectively.

Table 11. Physico-chemical parameter in the seaweed culture site on Day 90 (30.02.2022).

Parameters	High tide	Low tide
Temperature (˚C)	26	24
Salinity (‰)	23	24
pH	7.9	7.5
DO (%)	98	101
Conductivity (µS/cm)	37555	34234
FNU	40.1	42.8
Phosphate-phosphorus (PO_4-P) (mg/l)	7.5	5.4
Nitrate-nitrogen (NO_3-N) (mg/l)	0.04	0.03
Nitrite-nitrogen (NO_2-N) (mg/l)	0.03	0.01
Silicate (SiO_3) (mg/l)	0.25	0.23
Ammonia (NH_3) (mg/l)	0.26	0.24

Dissolved Oxygen (DO) is a very important parameter since aquatic biota requires oxygen for both metabolic and respiration processes. For all living creatures, DO is a limiting element. DO is a basic requirement for the survival of aquatic organisms. 3-8 mg/l DO is required to support the seaweed cultivation industry (Tuwo et al. 2020). The difference in DO content caused by water masses moving and mixing. DO is a natural condition in open water, hence water conditions that are weak or low in DO are uncommon (Kannel et al. 2007).

DO levels at St. Martin's Island ranged from 5.5 to 6.2 mg/l, 4.1 to 4.9 mg/l in Bakkhali, and 5.0 to 6.1 mg/l in Inani (Islam et al. 2017). DO levels in the Rezu Khal seaweed culture site varied from 92 to 105% in this study. In Nuniachara, Cox's Bazar sadar, Bokhtiar et al. (2022) found an average of 7.2 mg/l. In an algae growth site on the Salimpur coast, Uddin (2019) found 3.8 to 5.8 ml/l DO. In an Indonesian *Eucheuma cottonii* growing site, Rahman et al. (2019) found 5-6.5 mg/l DO. In the surface water of a *Kappaphycus alvarezii* and *Spinosum* sp. culture site in Sulawesi Province, Indonesia, DO ranged from 5.50 to 7.41 mg/l (Sulistiawati et al. 2019). In St. Martin's Island, Bakkhali, and Inani, Hoq et al. (2016) found 6.9-7.2 mg/l, 5.8-6.8 mg/l, and 6.1-7.2 mg/l, respectively. The concentration of DO in the St. Martin's Island was much greater than in Bakkhali and Inani. Another reason for the increased *Hypnea* production on St. Martin's Island is this.

One of the most significant criteria in evaluating water stability is the degree of acidity, or pH. Because each biota has different pH limitations, changes in the pH value in a water will alter the longevity of the biota. The input of garbage from land (rivers) to the aquatic environment causes an increase in pH value from the estuary to the high seas. The pH of sea and coastal waters is typically steady and falls within a narrow range, usually between 7-8 (Akib et al. 2015). Buffering capacity, namely the presence of carbonate and bicarbonate salts, influences pH. (Kautsari and Ahdiansyah, 2015). In Nuniachara, Cox's Bazar Sadar, Bokhtiar et al. (2022) found an average pH of 8.0. In an algae growth site on the Salimpur coast, Uddin (2019) reported a pH of 7.2 to 8.4. In an Indonesian Eucheuma cottonii cultivation site, Rahman et al. (2019) found pH 6.4-6.5. The pH of the surface water at a seaweed growth location in Sulawesi Province, Indonesia, ranged from 7.71 to 8.10. (Sulistiawati et al. 2019). In St. Martin's Island, Bakkhali, and Inani, Hoq et al. (2016) found 8.0-8.5, 7.4-7.5, and 7.6-8, respectively. Lower salinity could explain the significantly lower pH in Bakkhali.

Soil Quality Parameters

Seaweed cultures alone have a tendency to lower the pH of the system, whereas animal wastes are acidic. A good pH balance can be achieved with care (Colt and Huguenin, 2002). The ideal pH range for seaweed cultivation is between 7.0 and 8.5. (Rosyida et al. 2021). The depositional soils on St. Martin's Island have pH values ranging from 5.23-6.23 (Salam, 2020). Uddin (2019) measured soil pH at a Catenella nipae growing site on the Salimpur coast and found it to be 5.9-6.7. Grant (1981) recoded the inter-tidal soil pH of North Inlet, South Carolina, USA, which ranged from 7.6 to 8.1. In bottom silt taken from the lower Meghna river estuary, Islam (2016) found pH values ranging from 6.35 to 6.85. The availability of phosphorus is affected by soil pH and organic matter degradation rates. The soil pH in the culture site in this study ranged from 4.8 to 6.4 (Table). The maximum pH (6.4) was observed after 45 days of culture, whereas the lowest was recorded after 30 days. In the seaweed culture site, soil temperatures ranged from 21 to 26 degrees Celsius. The maximum temperature was discovered early in the culture period, and the minimum temperature was discovered after 15 days of seaweed culture (Table).

Table 12. pH and Temperature of soil collected from culture site.

Time	pH	Temperature (°C)
0 days	6.2	26
15 days	5.4	21
30 days	4.8	23
45 days	6.4	22
60 days	6.1	22
75 days	5.7	24
90 days	5.9	23

Proximate Analysis

Seaweeds include a variety of nutrients, including protein, lipids, carbohydrates, fiber, and minerals. Ash makes up more than 30% of the dry weight of marine algae and contains a variety of minerals, vitamins, and other compounds (Vijay et al. 2017). Seaweeds have a high nutritional content and are utilized as human food in a variety of cultures. Presently, there are 42 nations in the globe with reports of commercial use of seaweeds. China is the most powerful, followed by North Korea, South Korea, Japan, the Philippines, Chile, Norway, Indonesia, the United States, and India. These top 10 countries account for nearly all of the world's commercial seaweed consumption (Khan et al. 2007). The proximate composition of the present study documented in Table

Table 13. Proximate composition (%) of *Hypnea musciformes* and *Gracillaria lemaneiformis* collected from Rezu Khal seaweed culture site.

Sampling date	Species	Ash	Moisture	Protein	Lipid	Carbohydrate	Fiber
01.12.2021	*Hypnea musciformes*	9.21	23.05	17.11	0.81	45.11	4.71
	Gracillaria lemaneiformis	10.21	20.28	16.9	0.22	47.48	4.91
15.12.2021	*Hypnea musciformes*	12.12	15.57	17.18	0.50	50.11	4.52
	Gracillaria lemaneiformis	16.30	8.78	17.01	0.91	52.12	4.88
30.12.2021	*Hypnea musciformes*	21.01	22.24	14.21	2.19	34.81	5.11
	Gracillaria lemaneiformis	18.09	21.24	15.12	2.31	37.44	5.80
15.01.2022	*Hypnea musciformes*	16.23	23.68	8.11	0.56	45.91	5.51
	Gracillaria lemaneiformis	14.22	22.24	9.52	0.70	47.11	6.21
30.01.2022	*Hypnea musciformes*	13.22	37.08	8.92	0.64	34.92	5.22
	Gracillaria lemaneiformis	10.99	36.03	9.54	0.81	37.73	4.90
15.02.2022	*Hypnea musciformes*	13.22	15.45	12.10	0.61	54.11	4.51
	Gracillaria lemaneiformis	14.13	24.79	10.37	0.90	45.13	4.68
30.02.2022	*Hypnea musciformes*	10.11	31.22	14.12	1.51	37.33	5.71
	Gracillaria lemaneiformis	10.93	33.9	12.11	0.93	36.22	5.91

Minerals and heavy metals

Seaweeds have recently sparked interest due to their nutritional value, quantity, and ability to absorb metal elements through biosorption (Selmi et al. 2021). Despite the large number of publications published on the chemical composition of seaweeds to date, only a few papers have looked at metal uptake in macroalgae (Circunciso et al. 2018). Seaweeds are thought to acquire minerals and heavy metals due to the biochemical nature of their cell wall polysaccharides, according to these authors (Ahmed et al. 2021). Mineral content varies significantly among seaweed families, genera, and species depending on marine environmental conditions, geographical location, and harvesting period (Panahi et al. 2019).

Table 14. Heavy metals and minerals content (mg/kg) of *Hypnea musciformes* and *Gracillaria lemaneiformis* collected from Rezu Khal seaweed culture site.

Sampling date	Species	Ca	Mg	Cu	Fe	Mn	Zn	Ni	Pb	Cr
01.12.2021	*Hypnea musciformes*	870	9800	8.44	6200	14.6	23.1	12.33	2.71	0.4
	Gracillaria lemaneiformis	953	9580	9.66	5940	16.5	34.2	13.35	3.75	0.5
15.12.2021	*Hypnea musciformes*	1000	9721	9.11	6324	11.1	31.0	9.0	2.22	0.01
	Gracillaria lemaneiformis	808	9301	10.0	6100	12.5	28.1	7.23	2.31	0.2
30.12.2021	*Hypnea musciformes*	540	9200	10.89	10200	6.0	43.1	11.1	4.5	0.4
	Gracillaria lemaneiformis	602	9001	8.79	9800	7.9	32.1	12.3	3.9	0.7
15.01.2022	*Hypnea musciformes*	677	9840	10.81	6840	8.2	22.1	15.75	4.3	0.35
	Gracillaria lemaneiformis	698	8500	9.89	4590	6.0	20.1	12.15	4.65	0.86
30.01.2022	*Hypnea musciformes*	535	3600	10.0	4200	12.0	32.2	8.25	3.21	0.65
	Gracillaria lemaneiformis	1012	5400	9.97	3600	8.0	24.5	11.5	2.31	0.83
15.02.2022	*Hypnea musciformes*	847	8400	13.27	6600	9.6	23.1	13.95	3.45	0.68
	Gracillaria lemaneiformis	786	6362	10.49	3750	7.0	28.9	7.2	3.1	0.87
30.02.2022	*Hypnea musciformes*	901	10080	11.59	12600	8.0	32.2	12	4.5	0.34
	Gracillaria lemaneiformis	728	9600	12.22	8490	10.1	37.2	18	7.35	0.18

Challenges

Seaweed cultivation holds great economic potential. It also offers development and social alternatives in underprivileged coastal communities throughout the world, where over-fishing is often rife. Although aquaculture of seaweed in Rezu Khal is good but few challenges resulted low production (Below). If these challenges can minimize, seaweed production will increase substantially.

Sedimentation

The Rezu Khal is very dynamic. There is a story about the Khal that it kills people. The sand of this Khal moves every day. Veen if you put your establishment under 5 feet under water during low tide, you will find one part of establishment go under sand suddenly. Moreover, discharge water from Niribili hatchery also responsible for sedimentation. There is drain from Niribiili hatchery that bring sand and mud from upstream. As a result, turbulence and sedimentation increased. Sometimes, seaweed covered by sediment and reduce seaweed growth (Fig.). Sometimes seaweed die if they remain under sediment for longer period.

Figure 10. Sedimentation during culture.

Eutrophicated water

In the present study, there was intrusion of chemical mixed water or eutrophicated water from the nearby tilapia hatchery (Niribili Monosex Tilapia Hatchery). The growth of seaweed was very good, but one day seaweed in one corner of net was found dead (pale color). But what was the cause of this sudden death was not clear. Since water quality was good. After close inspection, the hidden cause was identified. The cause was chemical mixed water (green in color) discharge from Niribili hatchery (Fig.). They discharge eutrophicated water just before sunset and after sunset.

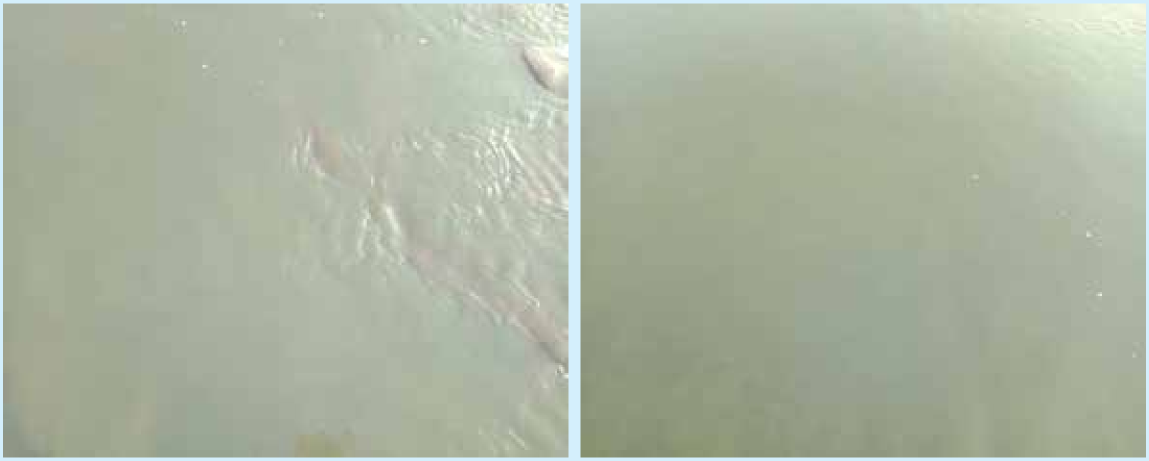


Figure 11. Chemical mixed or eutrophicated water intrusion in culture area.

Hermit Crab

Hermit crab is just like a sharp blade. It cut down the seaweed very smoothly. This crab was found in huge number in the cultivation site. They stick to the seaweed and cut the seaweed when it was growing well (Fig.). Most probably, this crab use seaweed as their habitat. They take food and nutrition from seaweed. As a consequence, they cut seaweed and these seaweeds washed out with current velocity. For this, the growth of seaweed retard and production is reduced.

Figure 12. Hermit crab in culture site that cut seaweed abruptly.

Current Velocity

Current velocity is very important for seaweed cultivation. In the present study, current velocity both in low tide and high tide was not good for seaweed cultivation. Since the cultivation was executed using net and long line method, when seaweed grow well, they are washed away with the current. As there was no barrier or protection to prevent seaweed from washed out. The current velocity at the seaweed cultivation location has an average speed of between 1.5-10 cm/s (Rahman et al. 2019). In nutrient-rich locations, current velocity of around 10 cm/s are sufficient to support the potential of seaweed cultivation (Mustafa et al. 2017). Dynamics stability of current velocity, very supports to the process of nutrients mixing and chlorophyll-a distribution to be utilized by the macroinvertebrate community (Schoen et al. 2013; Zulhaniarta et al. 2015).

Figure 13. Current velocity in the culture site that take away seaweed.

Garbage

Garbage like polythene bags, polythene ropes, nylon ropes, chips packets, discarded wood and torn part of trees are common in the culture site (Fig.). During low tide, culture has to clean. Otherwise, these wastes cover (mostly polythene) the seaweed and reduce growth. These garbage mainly come from local areas during high tide. Fishermen also throw polythene and other waste into the Khal. Mermaid Resort along the Khal is the main contributor of garbage. Everyday they throw their wastes materials into the Khal. As a result, cleaning have to perform every day, otherwise growth will hamper.

Figure 14. Different garbages in the culture site.

Exotic/unwanted sp.

During the month of March and April, the natural growth of Enteromorpha sp. is proliferative in the Rezu Khal. They washed away from their natural bed and stuck to the net and rope of culture site (Fig.). These Enteromorpha sp. stick to the cultured species and compete with the species for space and nutrition. As a result, during March and April the growth of target seaweed is lesser than the Enteromorpha sp. Ultimately, they become dominant species and reduce cultured species growth.

Figure 15. Unwanted Enteromorpha sp. that reduce target seaweed species.

Kayaking and engine boats

At Rezu Khal bridge, there is facilities of Kayaking named “Cox-Kayaking”. People used to have fun with Kayaking. But sometimes they come to the culture site and damage seaweed unintentionally. Besides, fishing boat also passed near the culture site and make strong current that uprooted the seaweed. Moreover, small scale fishermen fishing near or in the culture site since they get huge fish near or in the seaweed culture site. Fish use seaweed culture site as feeding and nursery ground. Fishermen cast their net in the culture site during night.

Figure 16. Cox kayaking in the Rezu khal adjacent to cultivation site.

Cost Benefit Analysis

People in Bangladesh are still not aware of the seaweed potential area. A few people are involved in seaweed cultivation in the south-eastern and south-western coasts of Bangladesh. Seaweed culture can be introduced in areas suitable for their cultivation by familiarizing poor farmers with cost-effective technology. Seaweeds can be cultivated using indigenous materials such as bamboo and rope. As seaweed cultivation requires a low quantity of inputs provides good returns and also employs many people. Seaweed culture can be a good industry for coastal communities in Bangladesh. Apart from its export potential, introduction of seaweed cultivation in the country's coastal areas could provide an alternative source of income for the people.

This cost benefit analysis was done for marginal farmers who can change their livelihood status doing seaweed cultivation.

Table 15. Total cost for one 5x5m plot.

Items	Cost
Net	400
Bamboo	200
Float	120
Seed	800
Total	1520 tk

Total return

Price of 1kg fresh seaweed	50 tk
After 15 days, avg. growth	15 kg
Total selling price (for 1 plot, for 12 phase)	50x15x12= 9000 tk
Total selling price (for 5 plots, for 12 phase)	5x9000=45000 tk
Total profit/income in 6 months	Total selling price-total

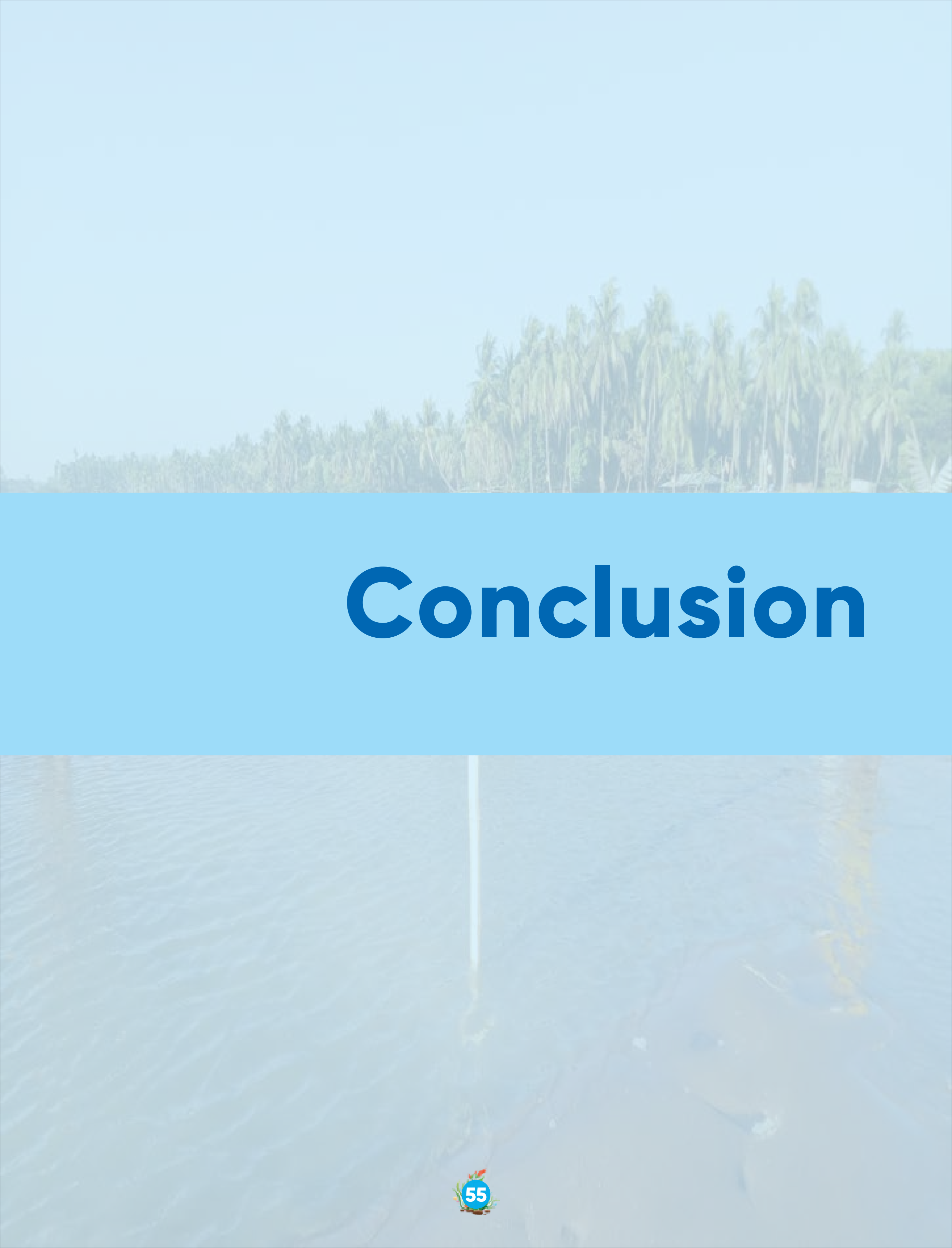
cost=45000-7600=37400 tk

Net profit in 6 months from 5 plots	**37400 tk**

Recommendations

Recommendations

- ♣ Intensive care needed for optimum growth.
- ♣ Regular monitoring of water quality parameters is needed.
- ♣ A new culture method named **“Multitrophic Box Method”** should be applied next year to minimize the challenges.
- ♣ Culture should be done in the off shore region of the sea.
- ♣ Experimental cultivation should cover more area to get better findings.
- ♣ Funding should be more and released within time.



Conclusion

Conclusion

Seaweed cultivation has great potential to contribute in national economy. It can be a great source of income for coastal community. It can be an alternative source of income for fishermen during ban period. Women can play important role in seaweed cultivation and its processing. Seaweed can change the economic structure of the coastal people by improving their livelihood status. National economy can be changed by meeting local demand and exporting. In the present study, Rezu Khal found as suitable site for seaweed cultivation. The growth of *Gracillaria lemaneiformis* and *Hypnea musciformes* was massive. *Sargassum oligocystum* survive and growth was good but not found not up to the mark. The findings indicate that Rezu Khal is suitable for these studied species culture. Having few challenges, growth rate was good. Few challenges were minimized and rest can be minimized as well. To meet the dream of bule economy seaweed can be a great component.

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Appendix-1

Photos of working

Appendix-1:

Photos of working

Figure 17. Plantation phase of seaweed cultivation in Rezu Khal.

Figure 18. Growing phase of seaweed cultivation in Rezu Khal.

Figure 19. Harvesting phase of seaweed cultivation.

Figure 20. Happy moments during working.

Figure 21. Md. Abdur Rahim Khan (Honorable Joint Secretary, MoC) visited the seaweed cultivation site

Appendix-2

Publications & Media Coverage

Appendix-2:

Publications & Media Coverage

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Assessment of Carbon Sequestration Capacity of Seaweed in Climate Change Mitigation

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Abstract: Carbon (C) cycling is being influenced by global climate change, which is altering the primary productivity and the rate at which carbon is fixed, released and stored in vegetation systems on Earth. Carbon sequestration is recognised as the storing of carbon dioxide (CO2) and other kinds of carbon for a long time. A selective atmospheric carbon-based anthropic enrichment causes an environmental catastrophe, which necessitates methods of mitigation. Algal primary production (which includes cyanobacterial algae, microalgal, and macroalgal) is a key pathway for C biosequestration in the ocean.

Is seaweed culture a sustainable approach for climate change adaptation?

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