Journal of Applied Life Sciences and Environment
https://jurnalalse.com

Original Article
https://doi.org/10.46909/alse-562098
Vol. 56, Issue 2 (194) / 2023: 231-244

SEAWEED CULTURE, POST-HARVEST PROCESSING, AND MARKET GENERATION FOR EMPLOYMENT OF COASTAL POOR COMMUNITIES IN COX'S BAZAR

Asrafi Md. FARHADUZZAMAN[1], Md. Suzan KHAN[1], Mohammad HASAN[2], Rashedul ISLAM[3], Mahadi Hasan OSMAN[1], Md. Neamul Hasan SHOVON[1], Sayeed Mahmood Belal HAIDER[4], Mrityunjoy KUNDA[5], Md. Tarikul ISLAM[4] and Md. Simul BHUYAN[4,5*]

[1]Palli Karma-Sahayak Foundation (PKSF), Dhaka, Bangladesh; email: farhadpksf@gmail.com; suzankhanfs@gmail.com; mahadi.hasan.osman@gmail.com; n.hasan.pksf@gmail.com
[2]Integrated Development Foundation (IDF), Cox's Bazar, Bangladesh; email: hasanimsf_cu09@yahoo.com
[3]Department of Marine Fisheries and Oceanography, Patuakhali Science and Technology University, Patuakhali, Bangladesh; email: rashed.pstu10@gmail.com
[4]Bangladesh Oceanographic Research Institute, Cox's Bazar-4730, Bangladesh; email: belal_13th@yahoo.com; taru@bori.gov.bd; simulbhuyan@gmail.com
[5]Sylhet Agricultural University, Sylhet, Bangladesh; email: kunda.arm@sau.ac.bd

*Correspondence: simulbhuyan@gmail.com

Received: Jun. 05, 2023. Revised: Aug. 11, 2023. Accepted: Aug. 23, 2023. Published online: Sep. 07, 2023

ABSTRACT. Seaweed farming is one of the aquaculture industries with the greatest growth rate worldwide, with an annual production of over 33 billion tonnes, and a value of USD$11.8 billion which is predicted to treble by 2024. The current study was conducted in the Bakkhali River estuary and set out to survey the seaweed cultivation, processing, marketing status of the seaweed farmers and evaluate its financial benefits. *Gracilaria lemaneiformis* and *Ulva intestinalis* were cultured using the rope methods. The yield of *G. lemaneiformis* and *U. intestinalis* was good (Ten 15 m long ropes were used in each of the 45 plots, produced 7770 kg of *G. lemaneiformis* in the first 15 days while using ten 15 m long ropes were in each of the plots of *U. intestinalis* produced 2300 kg). Water parameters viz. temperature, salinity, pH, DO and transparency were checked every 15 days. According to previous literature, winter was determined to be the most productive time for seaweed development in Bangladesh. Seaweed was processed by the sun drying method and sold to retail clients,

Cite: Farhaduzzaman, A.M.; Khan, Md.S.; Hasan, M.; Islam, Md.R.; Osman, M.H.; Shovon, Md.N.H.; Haider, S.M.B.; Kunda, M.; Islam, Md.T.; Bhuyan, Md.S. Seaweed culture, post-harvest processing and market generation for employment of coastal poor communities in Cox's Bazar. *Journal of Applied Life Sciences and Environment* **2023**, 56 (2), 231-244. https://doi.org/10.46909/alse-562098

neighborhood shops and markets, and representatives in Cox's Bazar, Bandarban, Rangamati and Khagrachari district, where *G. lemaneiformis* attracting the higher price. The income of seaweed farmers has increased more than in the previous years to maintain their family. Most of the farmers used raw seaweed as traditional medicine for the treatment of gastric problem (80%), diabetes (5%), blood pressure (3%) and cancer (2%). They also used seaweed as an additive with other vegetables, mutton and chicken. Education for coastal people is very difficult, but after cultivating seaweed, about 60% of farmers can afford their children's education cost and about 85% of the households had electric fans, while the majority had mobile phones. The cost-benefit analysis demonstrated that seaweed cultivation is highly profitable.

Keywords: coastal communities; employment generation; marketing; processing; seaweed culture.

INTRODUCTION

The term "seaweed" describes a huge variety of non-flowering macroscopic, multicellular, photosynthetic aquatic algae (Bhuyan, 2023) that have historically been collected in both the wild and in aquaculture all over the world. The majority of the 33 genera of seaweeds are harvested and grown economically are red and brown (McHugh, 2003).

Seaweeds are being used as an alternative source of food, fuel, essestial chemicals and livelihood means of the coastal peoples (Charrier *et al.*, 2017). Due to the nourishing benefits of seaweed, the majority of its output is used for direct human consumption or flavouring ingredients (e.g., sushi, salads, soups, desserts, sauces (Kılınç *et al.*, 2013). The remaining seaweed crop is used for fertiliser, food for animals, removal of pollutants from water, probiotics and biotechnological applications, in addition to the cosmetic, medical and food industries (Floros *et al.*, 2010; Osorio-Reyes *et al.*, 2023).

Seaweeds are a rich source of important nutrients, particularly minerals, agar, carrageenan and alginate. Seaweed contains amino acids (both essential and non-essential) and high-quality protein (Bhuyan *et al.*, 2022). The lipids are unsaturated and protect against cardiovascular diseases despite being present in modest amounts (Nestel *et al.*, 2015). Vitamins found in abundance in seaweed include beta-carotene, which is a precursor to vitamin A, as well as vitamins C, D, E and K. The high enzyme activity found in seaweed aids in the digestion of all these crucial minerals (El-Beltagi *et al.*, 2022; Ganesan *et al.*, 2020).

The cultivation of seaweed has become more common among the coastal populations as a means of subsistence income. Ecological appropriateness is a major factor in cultivation and parameters should be in the optimum range for optimum seaweed growth (Agyarko, 2017; Nor *et al.*, 2017). Different species of seaweed living in the same habitat have been linked to species-specific bacterial strains, according to a number of studies. The 'competitive lottery' explanation of how symbiotic bacteria drive algal growth is supported by the fact that different compositions of microbial communities with comparable functional properties can permit full seaweed morphogenesis (Ghaderiardakani *et al.*, 2017). Evidently, *Ulva*'s growth and development can be maintained in the

culture environment thanks to the stable and necessary core microbiome (Ghaderiardakani *et al.*, 2019; Wichard, 2023). To promote healthy growth, seaweed is typically grown in shallow intertidal zones where the water is frequently flushed. Seaweed farming requires the least amount of technological and financial resources compared to other forms of aquaculture, and it hardly ever used in feed or fertiliser applications (Islam *et al.*, 2020). Moreover, grow-out cycles in this cultivation are short, lasting no more than 60 days. Because of these advantages, seaweed culture has significantly improved the socioeconomic conditions of disadvantaged seaside peoples in developing countries. Seaweed culture has become the most promising source of income in several areas (Valderrama, 2012).

Bangladesh's coastline is around 710 km long, and in its coastal and estuarine environments, 200 species of seaweeds from red, green and brown algae have been identified (Towhidy and Alfasane, 2015). Many initiatives have been launched in Bangladesh, particularly during the past two decades, in recognition of its potential to promote the socioeconomic improvement of underprivileged coastal areas (Islam *et al.*, 2017; Zafar, 2007). Nevertheless, there remain huge knowledge gaps and a dearth of adequate documentation regarding socio-cultural aspects, economic opportunities, sustainability, potential risks and potential changes in the adaptability and livelihood pattern of the coastal communities as a result of their involvement in the production of seaweed (Krishnan and Kumar, 2010). The present study was carried out to: 1) assess the socio-economic context of the seaweed farmers, 2) assess the present status of seaweed post-harvest processing and market value chain, 3) determine risk factors and preventative actions and 4) assess potential interventions for productive seaweed production and commercialisation.

MATERIALS AND METHODS

Seaweed farming sites and resources

Seaweed was cultivated at Nuniarchhara (21°28′23.01″ N, 91°57′52.46″ E) and Rasterpara (Kurushkul) (21°30′14.35″ N, 91°59′25.02″ E) of Cox's Bazar along the coast of Bangladesh (*Figure 1*). According to the key informants, ideal salinity regimes and biological criteria determine the potential and ideal locations for seaweed production. Nevertheless, this needs extensive investigation and research efforts.

The most popular seaweeds grown in Bangladesh are *Gracilaria lemaneiformis*, *Ulva intestinalis* and *Ulva lactuca*. Although some seaweed species might be used in aquaculture in Bangladesh, the farmers have not yet looked into the possibilities of growing these species outside of the well-adapted options previously mentioned.

Commercial uses of agarophytes include the genus *Gracilaria* is employed in applications, such as food goods when the gel's strength is not essential. In other instances, *Gelidium* or *Gelidiella* are used to make bacteriological-grade agar, either alone or in combination with *Hypnea*.

On several coasts of Bangladesh, we frequently encounter *ulva*, a vivid green filamentous seaweed. During Novemer to March, seaweed may take over some shorelines, forming a short-pile carpet over rocks and stones that is brilliant green and hairy. In sandy terrain, clumps are occasionally visible. The long-line method and net method were found to be the most prevalent methods used in seaweed culture. The long-line approach was discovered to be the most popular technique used by seaweed farmers in Cox's Bazar during the study. This approach involves first gathering wild seaweed seeds from their natural habitat and then planting them in a long line (twisted rope) that is 25 to 30 m long, with each seed spaced 25 cm apart from the next.

Then, in the area of low tide (intertidal zone), the ropes are fastened to bamboo poles to keep it submerged throughout the culture period. The net method involves placing a square frame made of coir or nylon ropes (5x5 m^2) with a mesh size of 25 cm in the lower intertidal zone and supporting it with bamboo poles. Wild seeds are then planted at the same distance apart as in the long-line technique between the twists of the net ropes. Regular measurements of seaweed growth were made. During the production season, seaweeds are collected every 15 to 30 days, depending on the variety of species and mass growth.

Harvesting and processing of seaweed

Usually, seaweed is hand-picked from the cultivation locations. Harvests are occasionally cut by farmers using sickles or knives following a clean water wash and are sun-dried. If there is insufficient sunlight during processing, some farmers opt to dry their crops by air. After that, the dried seaweed are put into polyethylene bags. Depending on the type of demand and consumption, both raw and dried seaweed products are sold.

Data collection

To acquire information, respondents from various seaweed value chain segments were chosen. In this study, 200 seaweed farmers were interviewed, most of which were female and members of an NGO Integrated Development Foundation (IDF). To have a comprehensive understanding of this sub-sector, dealers, processors, entrepreneurs, academics and/or researchers and concerned government officials were consulted.

Secondary literature review

A substantial amount of published and peer-reviewed literature was consulted throughout the study. These documents assisted in gathering background data on the study areas and assisted in filling in the gaps in the empirical evidence.

Interviews

A significant portion of the information was gathered through in-depth interviews with seaweed growers, dealers and, distributors. In addition, Key Informant Interviews (KIIs) were carried out to learn about the conceptual and practical problems. KIIs have informed individuals with opinions based on the facts. In several situations, the interviews involved more than one session and used semi-structured checklists.

Figure 1 – Seaweed culture areas

To get indications and implications, the government, businesses and non-governmental organizations were consulted and questioned. Focus Group Discussions were conducted to confirm the primary data. To develop an economic study for it, scientific institutions were contacted for interviews to learn more about laboratory settings and cost-benefit theories.

Participatory observation

The beginning of the fieldwork in farming locations and the community involved watching potential project beneficiaries at work. This, combined with casual talks, made it easier to get to know the farmers and what they were up to. It took some time to see how the villages went about their everyday business. To get a better understanding of seaweed farming, processing, trading and quality control, players from the closest markets and the forward market were also consulted.

RESULTS AND DISCUSSION

The current study produced detailed observations and discussions on many socioeconomic aspects of seaweed cultivation in the coastal region of Cox's Bazar. A convergence of strategic concepts with consistent institutional and monetary backing for the essential measures aiming to improve the livelihood of seaweed growers and contribute to the blue economic (ocean economy) growth in Bangladesh is anticipated to follow the findings' depiction.

Demographics of the seaweed farmers

The seaweed farmers were between the ages of 22 and 55. Almost 20% of the interviewed seaweed farmers were men, and 80% of the responders were

women (*Figure 2*). Female seaweed farmers are found to be more active and attentive in al respect along with seaweed farming.

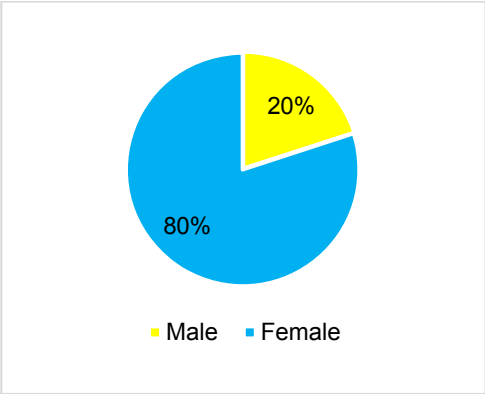

Figure 2 – Gender percentages of the respondents

About 55% of female respondents said that they were the head of their family. The average family size was 5, with a maximum of 7 and a minimum of 4.

Level of education

The coastal, rural areas of Bangladesh do not have appropriate educational infrastructure or facilities. The recent investigation also showed that only 8% of the respondents have access to education up to various secondary level grades, while 58% of the respondents did not obtain any formal schooling (*Figure 3*). Now getting benefits from the seaweed farming they can afford to send their children to school, approximately 60% of their children attend the school. Their economic situation has greatly improved because of the production and sale of seaweed.

Production of seaweed

Gracilaria lemaneiformis was cultivated using the long-line technique for the current study. Ropes of two lengths (15 m and 20 m) were used for producing seaweed. Ten 15 m long ropes were used for each of the 45 plots, produced 7770 kg in the first 15 days, on the 30th day produced 7225 kg, then with a steadily decreased trend 6555 kg, 6055 kg, 5235 kg and 4480 kg were produced respectively on 45th, 60th, 75th and 90th day.

The 20 m long ropes were constructed in 8 plots with 10 ropes in each of the plots. The production in 15 days was 1830 kg, in 30 days it was 1780 kg, in 45 days it was 1790 kg, in 60 days it was 1670 kg, in 75 days it was 1520 kg, in 90 days it was 1440 kg, in 105 days it was 1370 kg and in 120 days it was 400 kg.

Ten 15 m long ropes were used for each the plots for cultivation of *U. intestinalis*. 2300 kg of *U. intestinalis* was produced in 15 days. The production was gradually reduced and observed 2100 kg in 30 days, 1850 kg was in 45 days and 1420 kg was in 60 days. The average harvesting time for (*Kappaphycus alvarezii*) was 45 days and cultivated in long line or float in Nunukan Island, Indonesia (Shafitri *et al.*, 2019).

Income of the households

Due to its rapid culture cycle and the availability of easy, affordable farming technology, seaweed farming provides high financial returns (García-Poza *et al.*, 2020). The horizontal net and line technique of seaweed farming are the least expensive according to Ahmed *et al.* (2022). According to Ahmed *et al.* (2022) the line technique costs 1420 BDT (13.12 USD$), but the bottom net approach costs 2000 BDT

(14.48 USD$) (2022). The number of production cycles that farmers may run in a good season is between 4 and 6. Between 100 and 450 kg of live seaweed and between 30 and 50 kg of dried seaweed are produced annually by Bangladeshi farmers according to Ahmed *et al.* (2022). The range of each farmer's monthly agricultural revenue is between BDT 2000 (14.48 USD$) and 6000 (55.45 USD$). The total cost per square metre to produce seaweed on St. Martin's Island was BDT 1520 (14.05 USD$).

The benefit-cost ratio was 1.82, with a gross return of BDT 2801 (25.89 USD$) and a predicted net return of BDT 1281 (11.84 USD$) (Ghose and Hossain, 2021). Farmers produced *G. lemaneiformis* and *U. intestinalis* in the current survey. The majority of farmers (70%) invested 10151 BDT (93.81 USD$) in the production of *G. lemaneiformis* and made roughly 34251 BDT (316.54 USD$) in sales. *G. lemaneiformis* resulted in a profit of 24100 BDT (222.72 USD$) for the company. They spent 9300 BDT (85.95 USD$) on *U. intestinalis* and sold for 25840 BDT (238.80 USD$) in the market. Within three months, they generated a profit of roughly 16540 BDT (152.86 USD$) (*Table 1*). Seaweed farming increased the income of the farmers in Tanzania who were involved in the seaweed culture for 4-20 years. Key informant interviewees mentioned that the number of seaweed farmers increasing due to increase of income (Matoju *et al.*, 2022). The livelihood status of the coastal communities increases through seaweed cultivation in Nunukan Island, Indonesia (Shafitri *et al.*, 2019) which is supported the present study.

Standard of living and assets

Most of the seaweed growers in Nuniarchara and Nazirartek are immigrants searching for labor opportunities from Kutubdia, Moheshkhali and other areas in the vicinity. In essence, the residents of this area are transiently residing on government-owned land close to the coast.

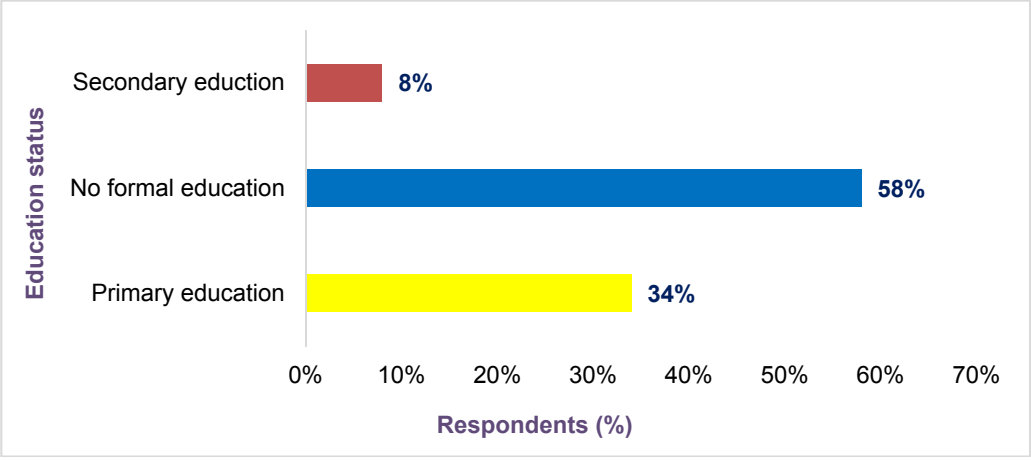

Figure 3 – Educational status of the respondents

Table 1 – Cost-benefit analysis of *Gracilaria lemaneiformis* (Group: 1-11) and *Ulva intestinalis* (Group: 12-13) seaweed at Cox's Bazar, Bangladesh

Species	Group no.	No. of farmers	Price of dried seaweed/kg	Income/ farmer	Production cost/farmer	Benefit (%)
Gracilaria lemaneiformis	1	5	182.0 ± 13.0	32960.0 ± 2942.7	9300.0 ± 0.0	254.4
	2	5	178.0 ± 14.8	30924.0 ± 4050.7	9300.0 ± 0.0	232.5
	3	5	177.0 ± 4.5	27882.0 ± 5348.6	9300.0 ± 0.0	199.8
	4	5	178.0 ± 19.2	27688.0 ± 5767.7	9300.0 ± 0.0	197.7
	5	5	188.0 ± 13.0	31668.0 ± 2003.0	9300.0 ± 0.0	240.5
	6	5	182.0 ± 13.0	30664.0 ± 4209.7	9300.0 ± 0.0	229.7
	7	5	188.0 ± 11.0	29800.0 ± 7247.1	9300.0 ± 0.0	220.4
	8	5	178.0 ± 19.2	28808.0 ± 9298.9	9300.0 ± 0.0	209.8
	9	5	194.0 ± 13.4	32148.0 ± 7918.2	9300.0 ± 0.0	245.7
	10	5	192.0 ± 8.4	55724.0 ± 4582.5	14300.0 ± 0.0	289.7
	11	3	186.7 ± 5.8	56433.3 ± 3141.7	14300.0 ± 0.0	294.6
	Overall		**183.7 ± 13.4**	**34251.7 ± 10719.5**	**10151.1 ± 1807.1**	**237.4**
Ulva intestinalis	12	5	132.0 ± 21.7	25550.0 ± 5663.5	9300.0 ± 0.0	174.7
	13	5	138.0 ± 16.4	26130.0 ± 2180.6	9300.0 ± 0.0	181.0
	Overall		**135.0 ± 18.4**	**25840.0 ± 4057.4**	**9300.0 ± 0.0**	**177.8**

They run the risk of being evicted from this location at any time by the authorities because they have no legal right to be on the property. The future of seaweed farming in these locations is questionable as a result of this harsh reality.

Bamboo, mud and corrugated sheets were used to build most of the houses. Some of them have roofs or shades made of tarpaulin. There were between three and five rooms in each of their dwelling quarters. Almost 85% of families had electric fans, and most of them (nearly 98%) had cellular (mobile) phones. Around 7% of the surveyed household had televisions. Only a relatively small number of homes were found to have a refrigerator and stereo systems.

Several of the houses included in the study had bicycles, motorcycles and battery- or CNG-powered autorickshaws, as well as rickshaw vans. A large portion of respondents have access to drinking water from tube wells, with only a small percentage occasionally drink boiling water. All of the respondents were found to be using latrines, most of which were pit latrines.

Health benefits of seaweed

Most of the farmers used raw seaweed as traditional medicine to treat gastric issues (80%), diabetes (5%), blood pressure (3%) and cancer (2%) *(Figure 4*). Some of the farmers believed that seaweed is an effective medicine for them and they don't need to buy medicine for these diseases. As a result, they could reduce their medicinal costs by using seaweed.

Seaweed as a cooking ingredient

Since seaweed farmers are mainly women, they used raw and dried seaweed in their cooking.

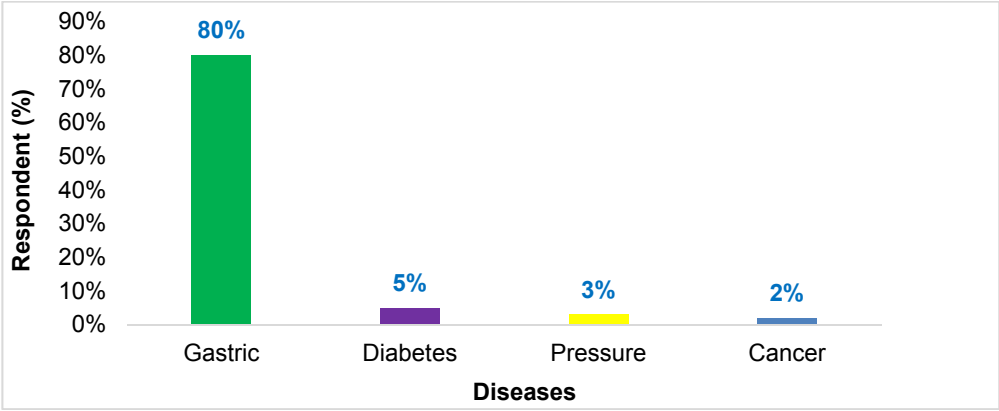

Figure 4 – Health benefits according to respondents

They used seaweed as an additive (spice) with other vegetables, mutton and chicken (*Figure 5*). They also used seaweed in salad, betel leaf, and cake among others. This type of use reduced their daily cost; hence their livelihood has improved more now than the previous time.

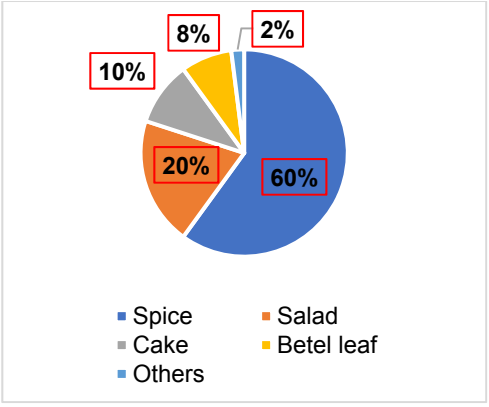

Figure 5 – Uses of seaweed among the seaweed farmers (respondents)

Systems in the seaweed market

In Bangladesh's coastal areas, seaweed production, harvesting, marketing and processing are well organized. There is no statutory requirement for the gathering and trading of wild seaweed. Seaweed farmers or collectors frequently transition into trade intermediaries or agents, which ultimately play a vital part in the seaweed supply chain and selling systems. Seaweed is supplied from three major sources: 1) local people collecting it from the wild; 2) self-governing or contract cultivation of seaweed using a variety of cultural techniques; and 3) commercial culture of seaweed using wage labor. Regarding their seaweed selling qualities, the farmers provided a variety of comments. About 80% of seaweed producers sell their products to merchants, while 5% to local agents and 15% to neighborhood residents.

At the farmers' end, fresh seaweed was sold for BDT 60–100 (0.55-0.92 USD$) per kilogram, while dried seaweed was sold for BDT 300–400 (2.77-3.70 USD$) per kilogram. The products that the seaweed farmers harvested were marketed to retail clients, neighborhood shops and markets and representatives in Cox's Bazar, Bandarban, Rangamati and Khagrachari (*Figure 6*). Moreover, certain goods were sold to South Korea, China, Burma and India.

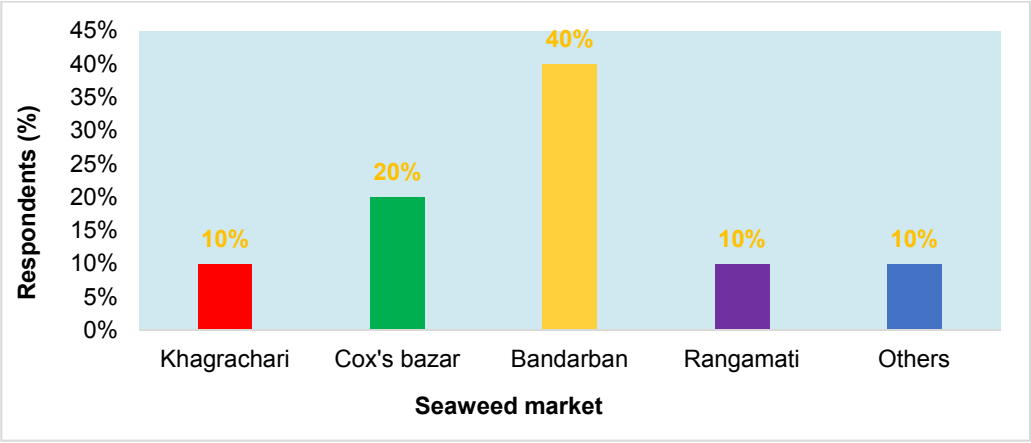

Figure 6 – Existing seaweed market for farmers in the country

Socio-economic impacts

By evaluating the changes in respondents' assets used to support their livelihoods, the socio-economic effects of seaweed farming were identified. Among them, 85% of the seaweed growers joined various community groups for savings and/or credit benefits, which were made possible by numerous NGOs, research and development institutes, or programmes like the Integrated Development Foundation (IDF), Resource Integration Centre (RIC), Asha, and Shakti Foundation. With the money they made from selling seaweed, some of them were able to buy or renovate their current homes, but relatively few members of the research group were able to purchase or lease land for agricultural farming or kitchen gardening. The ability of seaweed farmers to buy cattle, high-quality apparel and durable goods was also greatly enhanced by seaweed cultivation. Also, the respondents were able to use various electronic gadgets confidently. Through the revenue created by seaweed cultivation, some families were found to be able to resolve marital conflicts, resolve family concerns or prevent children from quitting school.

Seaweed farming has become a fresh, viable source of income for the coastal people in the research area. The responses also demonstrated their increased knowledge of the health advantages of seaweeds. The favourable effects of seaweeds on many health concerns relating to the digestive system, cardiovascular problems, hormonal imbalance, diabetic episodes and other inadequacies were found to be well-known to 95% of the farmers who were interviewed. They claimed that aggressive marketing of the advantages of seaweed will hasten the dynamics of this potential business. Therefore, it is anticipated that seaweed aquaculture will relieve the pressure on and prevent the overuse of fisheries and other natural resources with the right policy, financial, technological and institutional support. This chart illustrates how seaweed farming has affected the farmers' numerous sources of income. Livelihood assets and socio-economic impacts are outlined below in *Table 2*.

Table 2 – Livelihood assets and socio-economic impacts

Assets for living	Social and economic effects
Financial	- Joining community organisations for financial and/or credit benefits is encouraged by NGOs
Physical	- Purchase cattle, high-quality apparel and durable goods - Purchase or renovate their current home - Purchase or lease property for farming purposes
Human	- The ability to use various technological devices, such as Android phones, with confidence - Health advantages of seaweeds are becoming more well known
Social	- The ability to resolve marital disputes, - To resolve family conflicts, - And to prevent school abandonment among children
Natural	- A sizable coastal region with seaweed cultivation as a viable source of income

RECOMMENDATIONS

The project is being carried out to assure the market for seaweed aquaculture and its growth in Bangladesh. A major accomplishment of the project is the participation of women in seaweed cultivation. Together with the ongoing activities, several issues need to be addressed in the project for the following year.

Below, a few important recommendations are briefly discussed:

✓ Product development using produced seaweed;

✓ The seaweed industry is needed for agar, carrageenan and alginate production and post-processing;

✓ Boats with engines are needed for the collection of seaweed offshore;

✓ Land is needed for the drying and processing of seaweed along the coast;

✓ A storeroom and deep tube well are needed for the processing of cultivated seaweed;

✓ Bathing and toilet facilities are needed for seaweed farmers;

✓ A seaweed market channel analysis is needed;

✓ Ability to ensure appropriate coordination and synergy among the policymakers, research and development partners, producers and other stakeholders.

CONCLUSIONS

Seaweeds are a plentiful renewable natural resource along the coasts of Bangladesh. The cultivation of seaweed is a financially feasible source of income for rural communities, casting a particular hope for women's emancipation throughout the coastal areas. In this way, the production of seaweed can be aided by a sustainable market structure. The Cox's Bazar coast is appropriate for sustained seaweed farming and a marketing-based sector to support the blue economy (ocean economy). The system of good governance, which should enable coordinated collaboration among the policymakers, academic and research, development organisations and other stakeholders, can achieve the socio-

economic benefits and environmental resilience of seaweed farming. As a result, Bangladesh's seaweed industry stands a good chance of prospering. IDF is working efficiently in the cultivation and market generation of seaweed. They have engaged women in the culture, processing and marketing.

Author Contributions: Conceptualization, A.M.F. and M.S.K.; methodology, M.H. and M.S.B.; analysis, M.H.O.; investigation, M.H., M.R.I, M.H.O, M.N.S.; data curation, M.H; writing, review; supervision, S.M.B.H, M.K., M.T.I, M.H., A.M.F. and M.S.K.; software, M.H; writing original draft preparation, M.S.B. All authors declare that they have read and approved the publication of the manuscript in this present form.

Funding: Palli Karma-Sahayak Foundation (PKSF) for providing the fund for research.

Acknowledgments: The authors are grateful to Palli Karma-Sahayak Foundation (PKSF) for providing the fund for research. They also express heartfelt thanks to Integrated Development Foundation (IDF) for implementing the project in the field. The authors are also thankful to Bangladesh Oceanographic Research Institute for providing technical support.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Agyarko, K.A. Assessing the Socio-economic Benefits of Seaweed Production to the Rural Coastal Areas in Ghana. *International Journal of Advances in Science Engineering and Technology*. **2017**, 5, 32-36.

Ahmed, Z.U.; Hasan, O.; Rahman, M.M.; Akter, M.; Rahman, M.S.; Sarker, S. Seaweeds for the sustainable blue economy development: A study from the south east coast of Bangladesh. *Heliyon*. **2022**, 8, e09079. https://doi.org/10.1016%2Fj.heliyon.2022.e09079.

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

Bhuyan, M.; Abid Husain, S.; Chowdhury, E.; Bat, L. Assessment of Carbon Sequestration Capacity of Seaweed in Climate Change Mitigation. *Journal of Climate Change*. **2022**, 8, 1-8. http://dx.doi.org/10.3233/JCC220001.

Charrier, B.; Abreu, M.H.; Araujo, R.; Bruhn, A.; Coates, J.C.; De Clerck, O.; Wichard, T. Furthering knowledge of seaweed growth and development to facilitate sustainable aquaculture. *New Phytologist*. **2017**, 216, 967-975. https://doi.org/10.1111/nph.14728.

El-Beltagi, H.S.; Mohamed, A.A.; Mohamed, H.I.; Ramadan, K.M.; Barqawi, A.A.; Mansour, A.T. Phytochemical and potential properties of seaweeds and their recent applications: A review. *Marine Drugs*. **2022**, 20, 342. https://doi.org/10.3390/md20060342.

Floros, J.D.; Newsome, R.; Fisher, W.; Barbosa-Cánovas, G.V.; Chen, H.; Dunne, C.P.; et al. Feeding the world today and tomorrow: the importance of food science and technology: an IFT scientific review. *Comprehensive Reviews in Food Science and Food Safety*. **2010**, 9, 572-599. https://doi.org/10.1111/j.1541-4337.2010.00127.x.

Ganesan, A.R.; Subramani, K.; Shanmugam, M.; Seedevi, P.; Park, S.; Alfarhan, A.H.; Balasubramanian, B. A comparison of nutritional value of underexploited

edible seaweeds with recommended dietary allowances. *Journal of King Saud University-Science*. **2020**, 32, 1206-1211. https://doi.org/10.1016/j.jksus.2019.11.009.

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

Ghaderiardakani, F.; Califano, G.; Mohr, J.F.; Abreu, M.H.; Coates, J.C.; Wichard, T. Analysis of algal growth- and morphogenesis-promoting factors in an integrated multi-trophic aquaculture system for farming Ulva spp. *Aquaculture Environment Interactions*. **2019**, 11, 375-391. http://dx.doi.org/10.3354/aei00319.

Ghaderiardakani, F.; Coates, J.C.; Wichard, T. Bacteria-induced morphogenesis of *Ulva intestinalis* and *Ulva mutabilis* (Chlorophyta): a contribution to the lottery theory. *FEMS Microbiology Ecology*. **2017**, 93, fix094. https://doi.org/10.1093/femsec/fix094.

Ghose, T.K.; Hossain, M.I. Socioeconomic factors affecting profitability of seaweed culture in Saint Martin Island of Bangladesh. *Progressive Agriculture*. **2020**, 31, 227-234. http://dx.doi.org/10.3329/pa.v31i3.52127.

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

Islam, M.M.; Khan, M.S.K.; Hasan, J.; Mallick, D.; Hoq, M.E. Seaweed *Hypnea* sp. culture in Cox's Bazar coast, Bangladesh. *Bangladesh Journal of Zoology*. **2017**, 45, 37-46. http://dx.doi.org/10.3329/bjz.v45i1.34192.

Kılınç, B.; Cirik, S.; Turan, G.; Tekogul, H.; Koru, E. Seaweeds for food and industrial applications. In Food industry. In: *Food Industry*,Edition: 1 st. Edited by Innocenzo Muzzalupo, Intech, January, 2013, pp. 735-748. http://dx.doi.org/10.5772/53172.

Krishnan, M.; Kumar, R.N. Socio economic dimensions of Seaweed Farming in India. CMFRI Special Publication No. 104. Central Marine Fisheries Research Institute, Kochi, 2010.

McHugh, D.J. A Guide to the Seaweed Industry. *FAO Fisheries Technical Paper 441,* 2003.

Matoju, I.; Le Masson, V.; Montalescot, V.; Ndawala, M.A.; Msuya, F.E. A resilience lens to explore seaweed farmers' responses to the impacts of climate change in Tanzania. *Applied Phycology*. **2022**, 3, 132-148. https://doi.org/10.1080/26388081.2022.2091951.

Nestel, P.; Clifton, P.; Colquhoun, D.; Noakes, M.; Mori, T.A.; Sullivan, D.; Thomas, B. Indications for omega-3 long chain polyunsaturated fatty acid in the prevention and treatment of cardiovascular disease. *Heart, Lung and Circulation*. **2015**, 24, 769-779. https://doi.org/10.1016/j.hlc.2015.03.020.

Nor, A.M.; Gray, T.S.; Caldwell, G.S.; Stead, S.M. Is a cooperative approach to seaweed farming effectual? An analysis of the seaweed cluster project (SCP), Malaysia. *Journal of Applied Phycology*. **2017**, 29, 2323-2337. https://doi.org/10.1007/s10811-016-1025-y.

Osorio-Reyes, J.G.; Valenzuela-Amaro, H.M.; Pizaña-Aranda, J.J.P.; Ramírez-Gamboa, D.; Meléndez-

Sánchez, E.R.; López-Arellanes, M.E.; Martínez-Ruiz, M. Microalgae-Based Biotechnology as Alternative Biofertilizers for Soil Enhancement and Carbon Footprint Reduction: Advantages and Implications. *Marine Drugs*. **2023**, 21, 93. https://doi.org/10.3390/md21020093.

Shafitri, N.; Zulham, A.; Muawanah, U. Social structure of seaweed farmers in border areas: cases in seaweed farmers in Nunukan Island. *In IOP Conference Series: Earth and Environmental Science*. **2019**, 348, 012053. https://doi.org/10.1088/1755-1315/348/1/012053.

Towhidy, A.A.S.; Alfasane, M.A. Sublittoral Seaweed Flora of the St. Martin's Island, Bangladesh. *Bangladesh Journal of Botany*. **2015**, 44, 223-236. https://doi.org/10.3329/bjb.v44i2.38511

Valderrama, D. Social and Economic Dimensions of Seaweed Farming: A Global Review. IIFET 2012 Tanzania Proceedings, July 16-20, Corvallis, 2012.

Wichard, T. From model organism to application: Bacteria-induced growth and development of the green seaweed Ulva and the potential of microbe leveraging in algal aquaculture. *In Seminars in Cell & Developmental Biology*. **2023**, 134, 69-78. https://doi.org/10.1016/j.semcdb.2022.04.007.

Zafar, M. Seaweed culture (*Hypnea* sp.) in Bangladesh- Seaweed Culture Manual-1. Institute of Marine Science and Fisheries, University of Chittagong, Chittagong, Bangladesh. **2007**, 14.

Academic Editor: Prof. dr. Daniel Simeanu

Publisher Note: Regarding jurisdictional assertions in published maps and institutional affiliations ALSE maintain neutrality.