SEAWEED FARMING MANUAL

Prepared by

INFOFISH

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Dilmah CONSERVATION

Dilmah Conservation and Sustainability, Sri Lanka

July 2023

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The leading Asia-Pacific Fishery Service Centre since 1981

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PREPARATION OF THIS DOCUMENT

This Seaweed Farming Manual aims to provide basic technical guidance on the farming, harvesting and utilization of seaweed, focusing on *Eucheumatoids* (*Eucheuma* and *Kappaphycus)* species which contribute about 30% of global seaweed production. It is intended for individuals and communities involved in the seaweed sector on a small-scale.

The Manual is an outcome arising from a Letter of Agreement signed between INFOFISH and Dilmah Conservation and Sustainability, Sri Lanka, wherein the former was requested to provide consultancy support on seaweed farming, processing, utilization and markets. Dilmah selected Ceylon Aqua & Agri Sri Lanka as one of the stakeholders for the seaweed component under this project.

INFOFISH is an Intergovernmental Organization (IGO) set up by the Food and Agriculture Organization of the United Nations (FAO) to provide marketing information and technical advisory services for fishery products in the Asia-Pacific Region. It is headquartered in Kuala Lumpur and has 12 Member Countries, namely: Bangladesh, Cambodia, Fiji, Iran, Malaysia, Maldives, Pakistan, Papua New Guinea, the Philippines, Solomon Islands, Sri Lanka and Thailand.

INFOFISH sincerely acknowledges the contribution of Mr Gu Huan Qing (Philip Gu), Director, Favourite Technologies Pte Ltd, Singapore and Dr Dao Huy Giap, GreenAqua Pte Ltd, Vietnam for providing the necessary technical inputs and photographs in the preparation of this technical manual. The document was compiled by Sujit Krishna Das and Shirlene Maria Anthonysamy; layout and design by Mohd Syahir Zahardin; and editorial support by Firoza Buranudeen and Mohd Hazmadi Zakaria, all from INFOFISH.

FOREWORD

In addition to being an important source of food for human consumption through the centuries, seaweed contributes greatly towards poverty alleviation, coastal livelihood resilience, and building a thriving ocean economy at national and global levels. Widely recognised for their ecosystem services (in particular, bioremediation), various seaweed species are also of increasing importance in industries such as feed, pharmaceuticals, nutraceuticals and cosmeceuticals.

However, the global seaweed industry is still in its early stages and would therefore benefit from harmonized regional and international regulations, as well as knowledge on best practices and access to investments in order to innovate and improve value chains.

Responding to this need, a Letter of Agreement was signed between INFOFISH and Dilmah Conservation and Sustainability, Sri Lanka, wherein the former was requested to provide consultancy support on seaweed farming, processing, utilisation and markets.

One of the outcomes of the consultancy is this Seaweed Farming Manual, in which the steps and processes in seaweed farming, harvesting and processing are described in an easy-to-understand and comprehensive way. It is our hope that small and medium-sized enterprises (SMEs) in developing countries will find the Manual especially useful in their day-to-day operations.

On behalf of INFOFISH, I extend my appreciation to Dilmah Conservation and Sustainability for their support and collaboration in this process. We look forward to working more closely with the seaweed industry in other INFOFISH Member Countries in the near future.

Shirlene Maria Anthonysamy **Kuala Lumpur, July 2023**
Director, INFOFISH

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ABSTRACT

This technical manual provides step-by-step guidelines on *Eucheumatoid* seaweed farming, particularly with regard to the selection of sites and species, sourcing of seeds, transportation, farm design, suitable cultivation seasons and farming methods. It also discusses the challenges and issues, common diseases, practical remedies and preventive measures relevant to *Eucheumatoid* seaweed farming. Later sections of the manual contain useful information on the harvesting and post-harvest handling of seaweed, including sales and marketing; the roles of stakeholders and investors; the importance of food safety and seaweed value chain development; and a comparative economic analysis of a one-hectare seaweed farm. The manual also highlights the fact that Sri Lanka has a pristine coastline with huge scope for scaling-up seaweed farming. In this regard, collaborative efforts from public-private partnerships can bolster the process, enabling the country to improve seaweed value chains, attain better market access and ensure resilient and sustainable livelihoods for coastal communities.

Layout: Mohd Syahir Zahardin
Editorial Support: Firoza Buranudeen
Cover Photograph: INFOFISH/Sujit Krishna Das

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ABBREVIATIONS AND ACRONYMS

AP	Alcohol precipitation
BAP	Best Aquaculture Practices
cm	centimetre
CO_2	Carbone dioxide
e.g.	for example
FAO	Food and Agricultural Organisation of the United Nations
g	gram
GP	Gel press
ha	hectare
HABs	Harmful Algal Blooms
HDPE	High-density Polyethylene
IGO	Intergovernmental Organisation
IRR	Internal rate of return
kg	kilogram
km	kilometre
m	metre
m^2	metre square
mm	millimeter
MPAs	Marine Protected Areas
NGO	Non-government organisation
POS	Point of Sale
PET	Polyethylene terephthalate
PP	Polypropylene
ppt	Parts per thousand
RDS	Raw Dried Seaweed
SME	small and medium-sized enterprise
SRC	Semi-refined carrageenan
USD	United States Dollar
v-GHSD	v-groove hybrid solar dryer
VUSTA	The Vietnam Union of Science and Technology Associations
WHO	World Health Organisation of the United Nations
WoRMS	World Register of Marine Species
wt	Weight
%	Percentage
‰	Parts per thousand
°C	Degree Celsius

1. Introduction

Seaweeds are macro-benthic (large and attached) forms of marine algae which are among the main primary producers in the shallow areas of seas and oceans. They are able to manufacture or synthesise organic compounds from simple compounds such as water and carbon dioxide with the presence of light as a source of energy as all seaweed contain photosynthetic pigments in different forms, e.g. chlorophylls (green), carotenoids (orange, brown), phycobilins (red and blue) and other accessory pigments. Seaweeds are named after the dominant photosynthetic pigment they possess; thus more than 10 000 different species of seaweed fall into three groups: red (*Rhodophyta*), green (*Chlorophyta*), and brown seaweed (*Ochrophyta*). As seaweed requires light and substrates, their distribution is limited from the lower intertidal to the shallow subtidal zones in the marine environment. In general, the large forms are mainly concentrated in areas at, or a few meters below the zero-datum level.

This Manual will focus on the *Eucheumatoids (Eucheuma* and *Kappaphycus)* which contribute about 30% of global seaweed production.

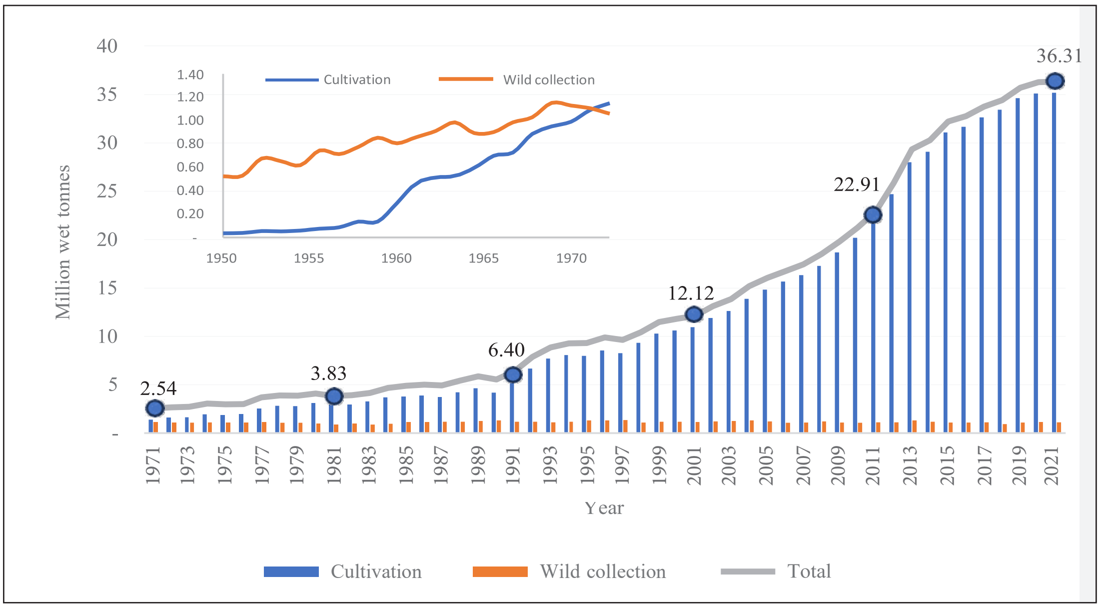
2. Seaweed Abundance and Distribution

In 1969, the amount of seaweed harvested from the wild equaled that from cultivation, at about 1.1 million tonnes. Half a century later, while wild collection remained at 1.1 million tonnes, cultivated seaweed had increased to 36.31 million tonnes, accounting for 97% of world seaweed production in 2021 (Figure 1). This increase was driven by rising pressure on food and feed supplies; the need for biological alternatives; and a growing understanding of the unique properties of seaweed, with the accompanying new innovations which have fueled excitement about their industrial potential globally.

Innovators in the seaweed value chains are trying to scale up seaweed production and develop new applications using seaweed biomass. However, there are important lessons to be learned from the current industry and also from the millions of people who depend on seaweed as a primary source of income. The majority of global seaweed production comes from Asia, where China, Indonesia, the Philippines, North and South Korea, Japan and Malaysia have the longest tradition of seaweed cultivation.

Although more than 10 000 species of seaweed have been described to date, the main commercially farmed species can be summarised into five major groups (Table 1).

Figure 1. Status and trends of global seaweed production, 1950-2021



Source: FAO, 2023

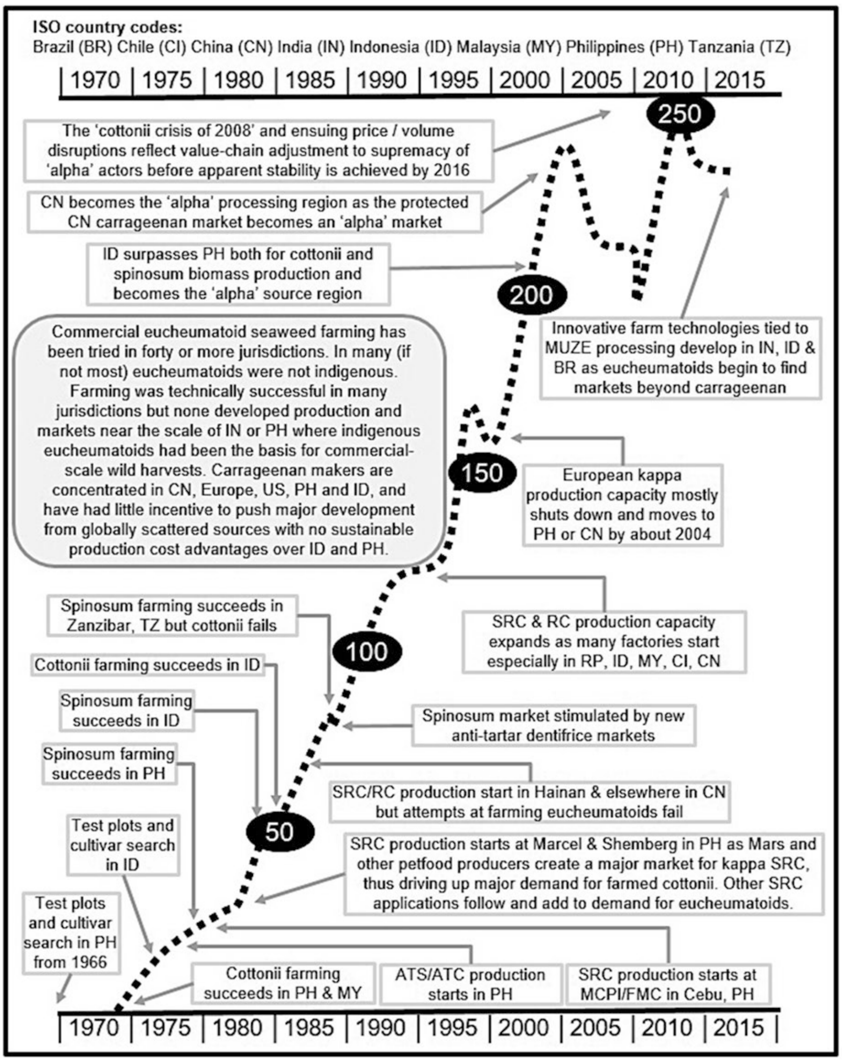
Table 1. Major seaweed production groups in 2019

	Species group	Climate	Industrial application	Production		
				Wet tonnes	%	Cycle
1	*Saccharina/Laminaria*	Cold water	Alginate, mannitol, iodine	12 411 987	34.7	8 months
2	*Undaria pinnatifida*	Cold water	Food (Wakame)	2 566 316	7.2	Yearly
3	*Porphyra/Pyropia*	Cold water	Food (Nori)	2 560 000	7.2	5 months
4	*Gracilaria*	Warm water	Agar	3 695 231	10.3	30-45 days
5	*Eucheumatoids*	Warm water	Carrageenan	11 685 174	32.7	45-50 days
6	Others			2 843 796	8.0	
	Total			**35 762 504**	**100**	

Source: Cai, 2021 and Poblete-Castro, et al., 2020

Eucheumatoid seaweed farming started in the Philippines, Malaysia and Indonesia during the 1970s. Today, these three countries are still the major producers, being responsible for more than 98% of global *Eucheumatoid* production (FAO, 2023). Indonesia is the 'alpha' source for seaweed which means that it is capable of supplying the entire global requirement for cultivated *Eucheumatoid* seaweeds, at prices that are hard to beat. On the other hand, China has become both an 'alpha' processing area and market that effectively protects them from processors outside the country (Figure 2). Chinese processors also sell carrageenan globally at highly competitive prices.

Figure 2. Schematic diagram depicting developments in the commercial farming of Eucheumatoid seaweed

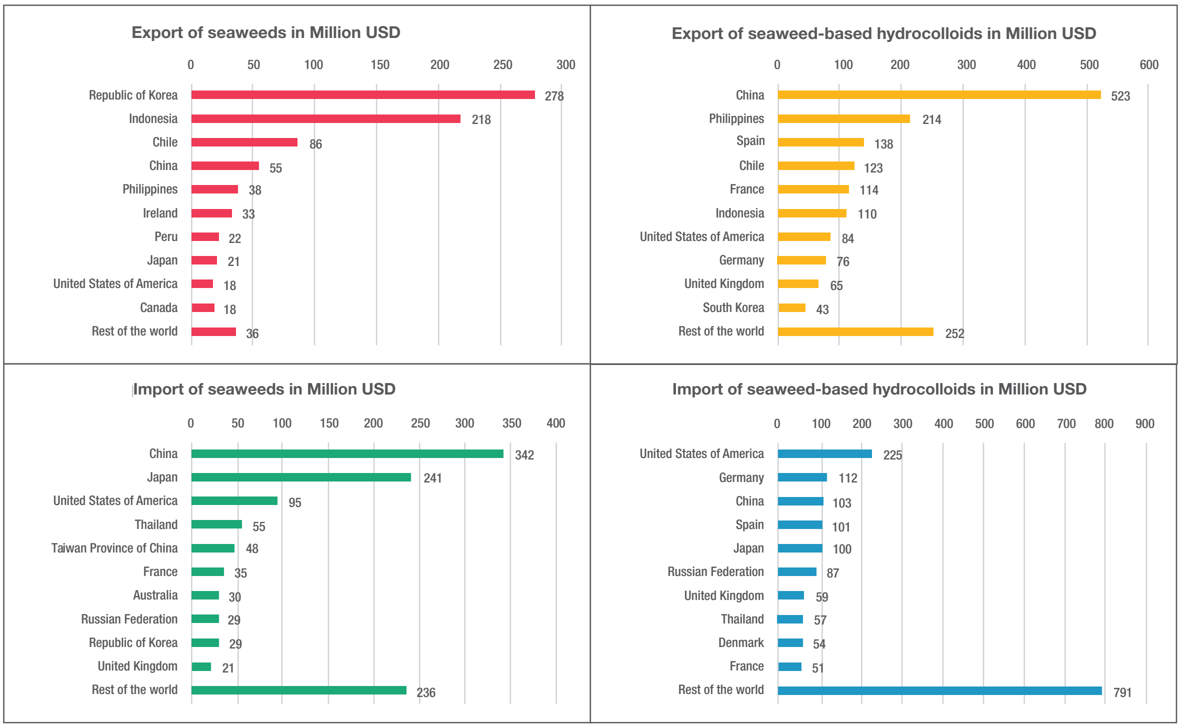


Reproduced from Neish, et al., 2017

3. Global Trade, Market and Utilisation of Seaweed Products

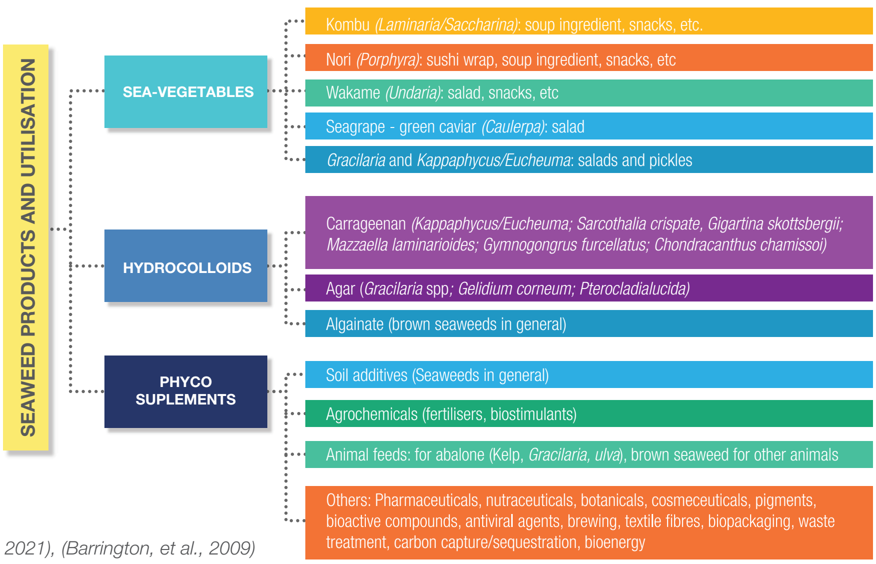
Recent data suggests that the global seaweed industry is worth more than USD 12 billion per annum, approximately 32 million tonnes per annum in volume (Poblete-Castro, *et al.,* 2020). Figure 3 shows that China is the largest seaweed processing country in the world. In 2019, the country imported 15% raw seaweed and exported 30% of the world's commercial value of seaweed-based hydrocolloid. The Republic of Korea and Indonesia are the two largest seaweed exporting countries. Seaweed exported from Korea is mainly cold-water seaweed for human food such as kelp, wakame and nori, whereas Indonesia exports mainly warm water seaweed such as *Kappaphycus/Eucheuma* for carrageenan processing. The market for seaweed is expected to grow steadily. This expansion will be reflected in the increased consumption of seaweed-based hydrocolloids mostly in Europe and the United States of America. Meanwhile, Asian countries (China, Japan, and Korea) are leading this market segment due to a high rate of traditional consumption of seaweed as human foods (Figure 3) (García-Poza, *et al.,* 2022), (Cai, 2021).

Figure 3. Top 10 exporters and importers of seaweeds and seaweed-based hydrocolloids, 2019



Notes:
1. Seaweeds include cultivated and wild collected commodities under HS120220, HS120221 and HS120229.
2. Seaweed-based hydrocolloids include HS130231 (agar), HS130239 (primarily carrageenan) and HS391310 (alginate)
Source: (Cai, 2021)

Figure 4. Seaweed products and utilisation



Source: (Cai, 2021), (Barrington, et al., 2009)

Seaweeds are mostly used as food (sea-vegetables) (70%) and other applications account for 30% including hydrocolloids (carrageenan, alginate and agar), feed, fertilisers, and chemicals (Figure 4) (Poblete-Castro, *et al.*, 2020). Seaweed-derived extracts (carrageenan, agar and alginates) account for almost 40 percent of the world's hydrocolloid market; the rest comes from certain animals, microbes and land plants (FAO, 2018). The most important commercial crops are *Saccharina, Kappaphycus/ Eucheuma, Gracilaria* and *Porphyra* (Table 1). *Porphyra* (Nori) and *Saccharina* (Kombu) are sold for food purposes at USD 16 000 and USD 8 000 per dry tonne, respectively (Poblete-Castro, *et al.,* 2020), whereas the warm water seaweeds *Kappaphycus/Eucheuma* are sold for carageenan purposes at only about USD 1 000 per dry tonne. However, some of the warm water seaweeds such as *Kappaphycus striatum* and *Eucheuma denticulatum* can also be used as vegetables such as salad, jelly and sweets like candy. Further research and promotion of consumption of warm water seaweed as human food should be advanced.

4. Prospects of Seaweed Farming in Sri Lanka

The coastline of Sri Lanka measures approximately 1 700 km containing many different varieties of seaweeds mostly along the west coast. About 320 seaweed species belonging to different families have been found. Out of these, about 15 commercially important species have been identified. The most common seaweed found in Sri Lanka is *Sargassum* spp, the main economic use of which is the production of alginic acid for the textile industry. Another valuable seaweed is *Gracilaria* spp; since the 1800s, naturally collected *Gracilaria* spp have been exported from Sri Lanka. It is also used locally as food such as porridge and a jelly drink (Jayasuriya, 1990) (Ginigaddara, *et al.,* 2018).

Cultivation of seaweed is still in the experimental stage in Sri Lanka. Previous attention had been given to *Gracilaria* spp which now faces severe threat of over-exploitation due to high demand for export. However, it has not been popular as a culture species, as farmers perceive it as having a fairly slow growth rate (Senarath, *et al.,* 2022).

In 2008, there was initial success in the farming of *K. alvarezii* in Sri Lanka. Since then, several trials in the commercial farming of this species have been carried out in various locations (Hayashi, *et al.,* 2017). Recently, a seaweed start-up and export company, Colombo-based Ceylon Aqua and Agri Pvt Ltd, has begun working with local communities to produce 20 tonnes of dried *Kappaphycus* seaweed per cycle or 90 tonnes per year (Senarath, *et al.,* 2022).

Sri Lanka's seaweed sector faces several challenges: scarcity of fast-growing and disease-resistant seeds; lengthy procedures for securing areas for sea-farming and a dearth of seaweed research and development. Nevertheless, seaweed is being extracted to produce semi-refined carrageenan, nutrient-enriched drinks, cosmetics, animal feeds, crop protection products and to provide ecosystem services. Hence, collaborative efforts including stakeholders from the public and private sector are required to bolster and scale-up seaweed farming. In this process, the country will be able to improve its seaweed value chains; enable better market access; and ensure resilient and sustainable livelihoods for the coastal communities.

Seaweed production and export statistics for Sri Lanka from 2017-2021 are provided in Table 2 for better understanding of the prospective seaweed industry. Source: (Sri Lanka Export Development Board, 2022, Personal Communication).

Table 2. Seaweed Production and Export in Sri Lanka (2017-2021)

Year	Seaweed Production (Wet weight), in tonnes	Exports	
		Quantity (tonnes)	Value (Million USD)
2017	692.33	62.0	0.041
2018	321.88	07.0	0.004
2019	246.89	17.0	0.01
2020	421.66	5.8	0.003
2021	218.15	17.0	0.01

5. Socio-economic and Environmental Importance of Seaweed

Seaweed farming is usually a family-managed business and is considered as one of the main sources of livelihoods for coastal communities. Ginigaddara *et al.,* 2018 surveyed 160 seaweed farmers from the Northern coastal part of Sri Lanka. The study concluded that seaweed farming in that area is reasonably profitable and generates considerable additional employment opportunities, based on an average of 25 seaweed rafts per farm. The estimated net present value (at a 20% discount rate) was USD 253 (implying an internal rate of return [IRR]= 43%), while the benefit-cost ratio was 1.19. The employment generation of the seaweed farming at the study area has been estimated as 3 392 man days (1 280 man days plus 2 112 woman days) per annum. Among the popular livelihood activities, seaweed farming is ranked second in highest importance for farmers, followed by fishing (Ginigaddara, *et al.,* 2018).

Thus with the expansion of sustainable seaweed farming in Sri Lanka, the socio-economic status of the marginal coastal communities (especially women) will be improved, and it will enhance the national export earnings through increased export of seaweed and seaweed-based products. Moreover, the sector helps to alleviate climate change impacts by absorbing carbon emissions, regenerating marine ecosystems, while promoting a circular economy by supplying more ‘blue food’ from the vast oceans.

6. Selection of Sites

Eucheumatoid seaweed can be grown in different water bodies and along water surfaces in ponds, lagoons, coastal fish cages and in islands, from depths of 0.5 - 15 m depending on the type of farming method such as fixed off-bottom, floating raft, hanging long-line and net bags. Crops can be grown all the year round in places which have favourable environmental conditions, especially in terms of salinity, temperature and wind, as long as they are suitable and stable or seasonal (Table 3).

Table 3. Parameters for site selection of Eucheumatoid farming

Parameters	Value/Description
License / permit required	Permit required from the local government
Typical farm area per smallholder farmer (in hectare)	Between 1/4 and 1 ha
Typical farm size (by culture line)	1 000 – 10 000 m
Distance from shore	Between 0.1 and 3 km
Water depth range	From 0.5 m - 15 m at low tide
Exposure of farm site	Both sheltered and open sea
Substrate beneath farm	Sand, stones, coral, seagrass
Water current	20 - 40 m/minute
Salinity (‰)	> 24 ppt and stable
Water temperature	26-29°C

7. Selection of Species

There are three species which are commonly farmed worldwide for carrageenan, *i.e. Kappaphycus alvarezii (Cottonii)*, (Figure 5), *Kappaphycus striatus (Cottonii-elkhorn)* and *Eucheuma denticulatum (Spinosum),* as depicted in Table 4. Overall, *Spinosum* requires less attention and is easier to grow than *Cottonii.* However, farmers prefer to grow *Cottonii* whenever possible, as they can get a much higher price (Table 5).

Table 4. Different species of Eucheumatoid seaweeds cultivated around the world Indicating corresponding farming techniques

Country	Species farmed	Shallow waters (1-3m LLT)		Deep waters (>5m LLT)						
		FOB	SFR	FS	HLL	MRLL	SW	TNB	B/NB	OR
Brazil			✪					✪		
Cambodia	Ka, Ks	✪								
China	Ka	✪								
Colombia	Ka, Ks, Ed		✪							
Equador	Ka		✪							
Fiji	Ka,Ks	✪	✪		✪					
Cambodia	Ka, Ks, Ed				✪					
India	Ka, Ks		✪						✪	✪
Indonesia	Ka, Ks, Ed	✪			✪					
Kenya	Ka, Ed	✪								
Kiribati	Ka	✪	✪		✪					
Madagascar	Ka, Ed	✪								
Malaysia	Ka, Ks, Ed	✪	✪		✪				✪	
Micronesia	Ka	✪								
Mozambique	Ka, Ed	✪	✪							
Myanmar	Ka		✪		✪					
Panama	Ka				✪					
Papua New Guinea	Ka	✪			✪					
Philippines	Ka, Ks, Ed	✪	✪	✪	✪	✪	✪			
Solomon Is.	Ka	✪								
Sri Lanka	Ka		✪							
Venezuela	Ka, Ed	✪	✪							
Vietnam	Ka, Ks, Ed	✪			✪				✪	
Tanzania/Zanzibar	Ka, Ks, Ed	✪			✪			✪		

Ka *Kappaphycus alvarezii;* ***Ks*** *Kappaphycus striatus;* ***Ed*** *Eucheuma denticulatum,* ***LLT*** *lowest low tide*, ***FOB*** fixed-off bottom, ***SFR*** single floating raft, ***HLL*** hanging long-line, ***MRLL*** multiple raft long-line, ***FS*** free swing, ***TNB*** tubular net bag, ***B/NB*** basket/net bag, ***OR*** octagonal rafts
Source: (Hayashi, et al., 2017)

Table 5. Market demand and prices for two carrageenan species

Scientific name	Commercialname	Carrageenan extract	Farm gate price for dried seaweed in 2022
Kappaphycus alvarezii	*Cottonii*	Kappa	0.9-2.88 USD/kg
Eucheuma denticulatum	*Spinosum*	Iota	0.42-0.67 USD/kg

Source: Hatch Innovation Services, 2022

Figure 5. Fresh Cottonii Seaweed, Kappaphycus alvarezii

Classification of Cottonii Seaweed

Kingdom	*Plantae*
Subkingdom	*Biliphyta*
Phylum	*Rhodophyta*
Subphylum	*Eurhodophyta*
Class	*Florideophyceae*
Subclass	*Rhodymeniophyceadae*
Order	*Gigartinales*
Family	*Solieriacae*
Genus	*Kappaphycus*
Species	***Kappaphycus alvarezii*** *(Doty) Doty ex P.C Silva 1996*

Source: World Register of Marine Species (WORMS)

8. Sourcing and Transport of Seeds

Seed production for *Eucheumatoids* is done by vegetative propagation via cuttings or through micropropagation techniques. About 100-200g of healthy and clean seaweed (intact, no scratches, no signs of disease and no sticky algae) is cut with a sharp knife to prepare new seaweed seedlings. The seedlings can be directly tied to the cultivation lines, with each seedling being 0.20 m apart. Tying seaweed to the cultivation line is carried out on land with the seedlings being irrigated or dipped in seawater to avoid drying out. The task is carried out by either family members (mainly women) or paid workers, who are paid per piece or line. Cultivation lines are then arranged in parallel and placed 0.2-1 m apart on the planting rig. Seeding information for *Eucheumatoids* is given in Table 6.

Sometimes seedlings (mainly from own harvests) are traded fresh between farmers at the current market prices. When transferring fresh seaweed from one place to another, it is necessary to take measures to cover the seaweed to avoid the sun and keep it moist. If the distance is close by, the seaweed can be put into bags during the transportation. It should be covered to prevent the seaweed from being exposed to the sun, heat, wind, rain and drying conditions. If the distance and transportation time is long, it is necessary to sprinkle seawater from time to time to keep the seaweed moist and fresh. When transporting long distances such as over 100 km, farmers must use trucks with refrigerated containers to keep the seeds at a temperature of 20-22°C. Upon arrival at the planting site, put the seaweed into the water immediately. The farmers can set a net under the water to keep the seaweed healthy and fresh before planting.

Table 6. Seeding information for Eucheumatoids

Parameters	Value/Description
Source	Mainly own harvest, sometimes neighbouring farmers, local collectors or from government agencies
Amount of seed	About 100 -200 g/seedling
Distance between seedlings	0.2-0.3 m
Seeding method (Tying)	Tie nylon cord directly on rope, Looseloop single line or double line rope method
Distance between cultivation lines	Varies among techniques and locations
Standard seeding/hour/person	Average 50 m/hour/person (from 30-100 m)

9. Seasons of Seaweed Farming

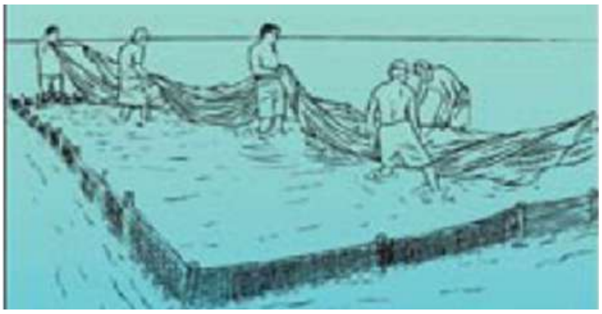
As mentioned in the site selection section, *Eucheumatoids* require stable salinity, temperature, and water flow. In tropical and subtropical regions, the classification of seasons based on rainfall is either "dry" and "wet", or in terms of temperature, "cold" winter and "hot" summer seasons. The weather has a great influence on seaweed productivity and quality. For example, under suitable cool seasonal conditions, the daily growth rate of the seaweed varies from 9-11% as compared to 4% in the hot season (Hayashi, *et al.,* 2017). Seasons also affect the biochemical composition of seawater, thus influencing the carrageenan quality of the seaweed. In addition, ice-ice disease, predators, epiphytes and typhoons occur seasonally. Therefore, knowledge of suitable seasons is important for successful seaweed farming.

10. Methods of Seaweed Farming

Seaweed farming methods include tying and cultivation techniques. Different types of seaweed farming methods are described below, together with their advantages and disadvantages for better understanding.

10.1. Tying techniques

Tying techniques meant to hold or keep seaweed in the farming area consist of: (i) Seaweed pens, (ii) Cages/Baskets, (iii) Tube nets, (iv) Tie-tie, and (v) Quick loops. The seaweed pen and floating basket methods are mostly used to hold the seaweed seedlings temporarily. The tubular net bag method is mainly seen in Brazil and Tanzania; this technique allows opportunities for future potential mechanisation. The tie-tie method is widely used in seaweed farming while for quick loops, 2-3 mm ropes are used to tie the seaweed. Plastic raffia strings are not used in the quick loop method, so that they will not be mixed with the harvested product. The time to tie and untie the rope is also quicker. However, this method has only been tested in Singapore, and needs to be trialled further before being applied in other seaweed farms. The advantages and disadvantages of various types of tying techniques are presented in Table 7.



(i) Seaweed pen (Teitelbaum and Lesire, 2003)

(ii) Cage/Basket (Hayashi, et al., 2017)

(iii) Tube net (Hayashi, et al., 2017)

(iv) Tie-tie (CD-CAAM, 2016)

(v) Quick loops. Lengths of 2-3 mm rope are used to tie seaweed without using raffia string

Table 7. Seaweed tying techniques and their advantages and disadvantages (i-v)

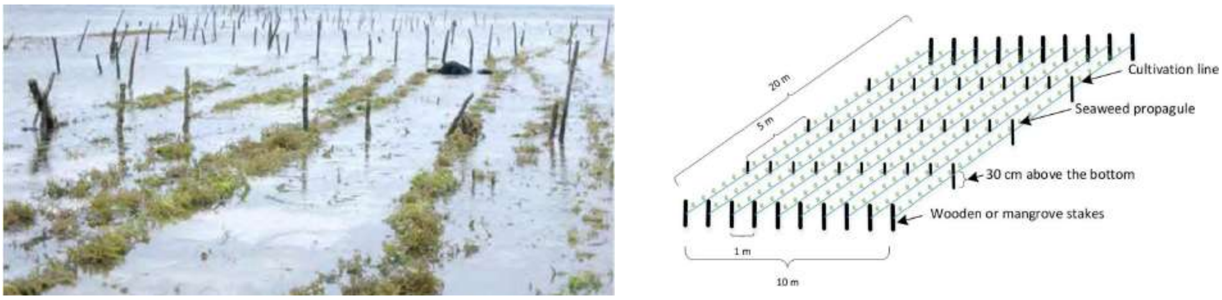
	Tying techniques	Advantages	Disadvantages
i	Seaweed pen	Seaweed pen protects the seaweed from being eaten by fish	Expensive and takes time to set up
ii	Cage/basket	A variety of cages/baskets can be used. They prevent epiphytes and are able to withstand bad weather conditions	Expenses are higher in terms of implementation and maintenance. Possibilities of biofouling etc
iii	Tube net	Lower susceptibility to weather conditions, uniform growth rate, useful in deep water with minimum infrastructure	More seedlings required, not user-friendly and can be costly
iv	Tie-tie	Easy to use, hence widely implemented	Time-consuming while tying propagules and separating the ties. Risk of tie contamination with the harvested seaweed
v	Quick loops	Faster in tying propagules. No risk of plastic contamination in the harvested seaweed	New method. Need to be tested and applied in more seaweed farms

10.2. Basic farming techniques

Water depth is the main criterion that determines the farming techniques along with looking at the site conditions, price and availability of equipment needed for a seaweed farm. Five main farming techniques include: (i) Fixed off-bottom, (ii) Bamboo floating raft, (iii) Hanging long-line, (iv) Multiple raft long-line, and (v) Spider web. The advantages and disadvantages of these techniques are presented in Table 8.

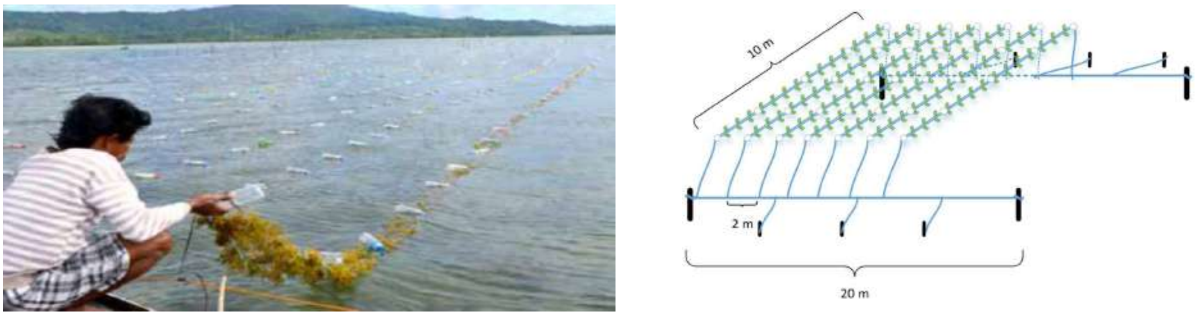
The fixed off-bottom and bamboo floating raft techniques remain the simplest and most suitable for shallow water of 0.5 - 5 m at low tide. The hanging long-line, multiple rafts long-line, and spider web techniques are suitable for more than 5 m water depth at low tide. The fixed off-bottom and hanging long-line techniques are the most commonly used. The cultivation lines should be arranged in the same direction as the water current at the site Figure 6 (i-v). Other modified techniques which can be adapted to suit local conditions while maintaining productivity, are presented in Figure 7 (i-iv). Moreover, the prerequisites, advantages and disadvantages of five main types of seaweed farming techniques has been displayed in Table 8.

Figure 6. Illustration of Five Main Farming Techniques (i-v)

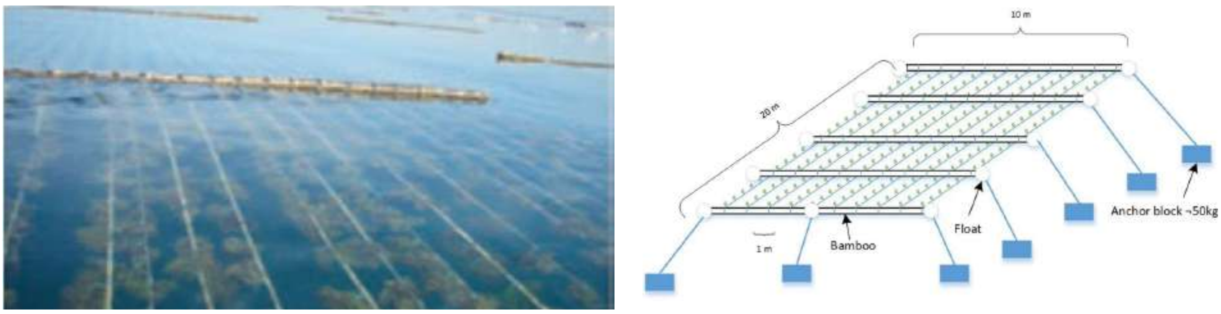


i. Fixed off-bottom *(CD-CAAM, 2016). 10 lines x 20 m = 200 m of cultivation lines for each plot of 200 m^2*

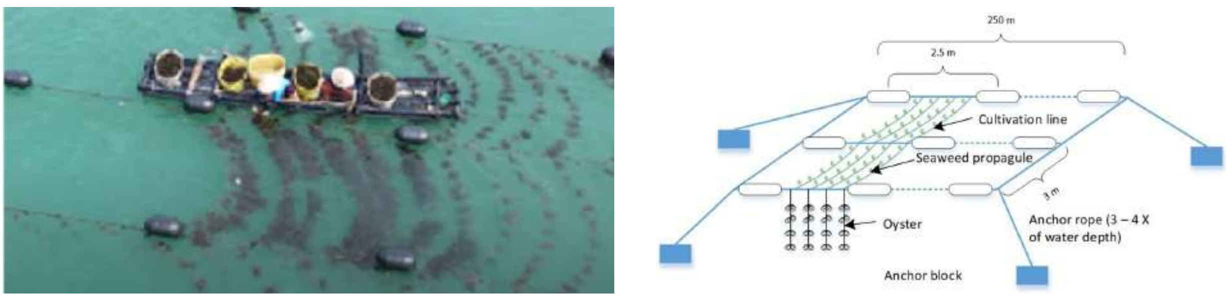
ii. Bamboo floating raft*. 20 lines x 3 m = 60 m of cultivation line for each raft of 13 m^2.*



iii. Hanging long-line *(CD-CAAM, 2016). 20 lines x 10 m = 200 m of cultivation lines for each plot of 200 m^2*



iv. Multiple rafts long-line *(Hayashi, et al., 2017). 10 lines x 20 m^2 = 200 m^2 of cultivation lines for each plot of 20 m^2*



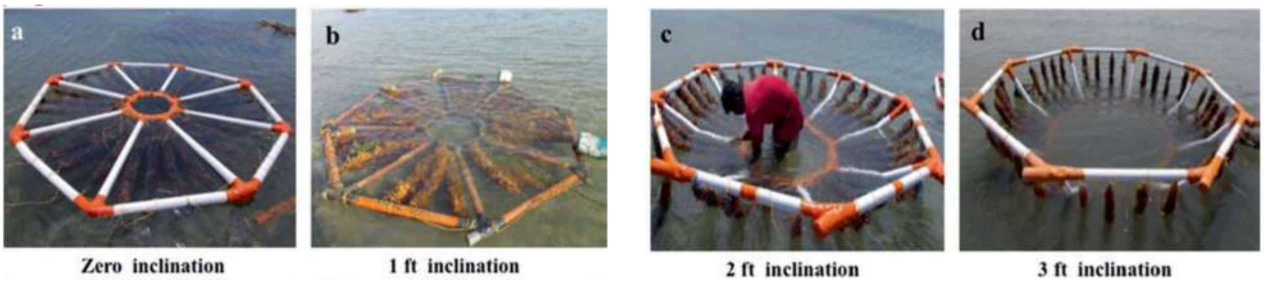
v. Spider web *(VUSTA, 2022).*

Table 8. Seaweed farming techniques and their advantages and disadvantages

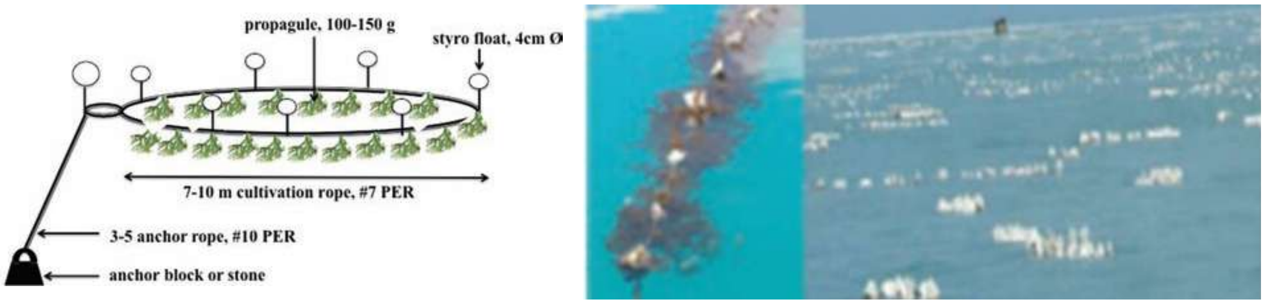
Prerequisites	Farming techniques				
	Fixed off-bottom	**Bamboo floating raft**	**Hanging long - line**	**Multiple raft long-line**	**Spider web**
Water depth (m)	0.5-1	1-5	1-10	>10	>15
Distance between cultivation lines (m)	1	0.15	2 (double lines)	1	0.5
Length per cultivation line (m)	20	3	10	20	3
Distance between ties (m)	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3
Anchor	Wooden stake	Wooden stake, sand bag, stone		Metal anchor, concrete block	
Floater	Not used/ PET bottles	Bamboo	PET bottles, styrofoam	Bamboo, plastic buoys	Plastic buoys
Other materials	Plastic raffia and various sizes of polyethylene ropes				
Advantages	Low investment cost. Easy to handle	Environmentally-and user- friendly. Easy to set up	Simple, low-cost, and effective	Useful for large-scale production, more economical, user-friendly	Higher productivity, possible polyculture (oyster)
Disadvantages	Vulnerable to bad weather, epiphytes	Sensitive to weather changes, no uniform growth	Sensitive to weather changes (high temperature).	Higher investment cost and maintenance	Epiphytic risks, sensitive to weather changes

Source: Johnson, et al., 2017

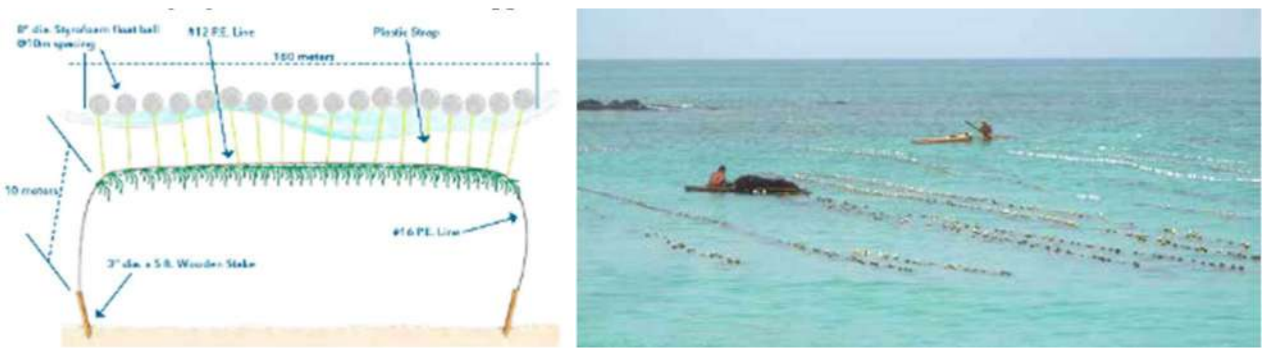
Figure 7. Modified farming techniques to suit local conditions (i-iv)



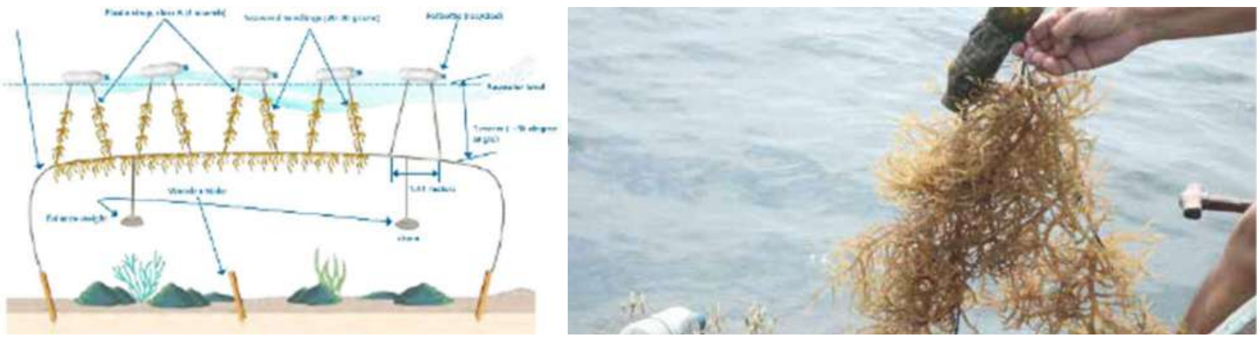
i) Polygonal raft technique *(Hayashi, et al., 2017). Easy to float, easy to handle, but expensive to implement.*



ii) Free-swing technique *(Hayashi, et al., 2017).*



iii) Monoline hanging *(CD-CAAM, 2016). Applied in wider, exposed, and deeper water areas.*



iv) Triangular technique *(CD-CAAM, 2016). Applied during the hot season. This technique keeps seaweed in deeper water, thus reducing the impact of the hot water surface.*

11. Designing Seaweed Farms

A typical seaweed farm should include several components to support the farming plot. They are: (i) Storage room (ii) Working shack (iii) Seed holding cage or pen (iv) Seaweed seedling banks (v) Several farming plots to rotate planting and harvesting every week (vi) Boat (vii) Drying platforms/systems and (viii) Warehouse to store dried seaweed while waiting for transport to market. The functions and description of the different farm components are described in Table 9 and the layout of a farm is illustrated in Figure 8.

Table 9. Farm components and their functions

Components	Functions/Description
1. Storage room	To keep planting material
Plastic raffia	- To tie seaweed propagules
Various sizes of polyethylene ropes	- To set up cultivation lines and anchor ropes
Recycled PET bottles	- To float cultivation lines
Wooden stakes/anchor bars or blocks	- To anchor the cultivation lines
Tools and equipment	- Knife, scissors, hammer, measuring tape, etc
2. Working shack	To: - To prepare seaweed cultivation lines - To select good seaweed seedlings - To tie propagules - To seperate tie-tie - To hold workers/people
3. Seed holding cage or pen	To hold seaweed seedlings
4. Seaweed seedling banks (In multiple sites and for different farming techniques)	To ensure seaweed quality in consecutive farming cycles
5. Farming plots (Multiple rotating plots. e.g., 5-7 farming plots to rotate planting and harvesting every week)	- To grow seaweed. Seaweed weight should increase 5-6 times after 45 days - To have consistent harvests and income as seaweed farming must be done every day, but may not take the whole day
6. Boat (Not always required)	- To transport and tie cultivation lines to the farming plots - To visit farms daily to remove floating debris, predators (sea urchins, crabs, sea stars) and monitor ice-ice disease - To transport the seaweed from farm sites to drying areas - To transport the dried seaweed to buying stations
7. Drying platforms/systems Cover with plastic at night or during rainy days	- To dry seaweed and keep them away from contamination by dirt and other materials - The seaweed will dry in 3 days when it's sunny and 5 days when it's cloudy or rainy
8. Warehouse	- To pack, weight, record and store dried seaweed while waiting for transport to market

Farming plots are important in any seaweed farm. Water depth is the key criterion in the design of the plots and selection of appropriate farming techniques (see Section 10.1). It is also important to have the right anchoring to hold down the farming plot; experience and local knowledge on wind, current, wave drift forces and sea bottom type should be considered in order to decide the weight and type of anchor. As a general rule, the length of the anchor rope should be 3-4 times more than the water depth when using a plow anchor and 2-3 times of the water depth while using concrete block anchors. The weight of the anchor (kg) should be 1.5 times the length of the seaweed farm (metres). If the seaweed farm is 100 m long, the weight of the anchors should be 1.5 x 100 = 150 kg.

12. Managing of Grow-out Farms

Eucheumatoids are usually farmed in cycles of 30 to 45 days (sometimes up to 60 days) and most farmers visit their farm daily. Besides setting up new lines and harvesting, farmers also adjust depths, and remove sediments and filamentous algae during visits. In some regions, a lot of sediment tends to accumulate on seaweed after heavy rains and freshwater runoffs.

Spinosum (Eucheuma denticulatum) is easier to farm and is more resistant to ice-ice syndrome than *Cottonii/(Kappaphycus* spp.*)*. When the season is not ideal for growing *Cottonii,* farmers can consider growing *Spinosum* instead. The grow-out information for *Eucheumatoids* is illustrated in Table 10.

Figure 8. Illustration of a seaweed farm layout

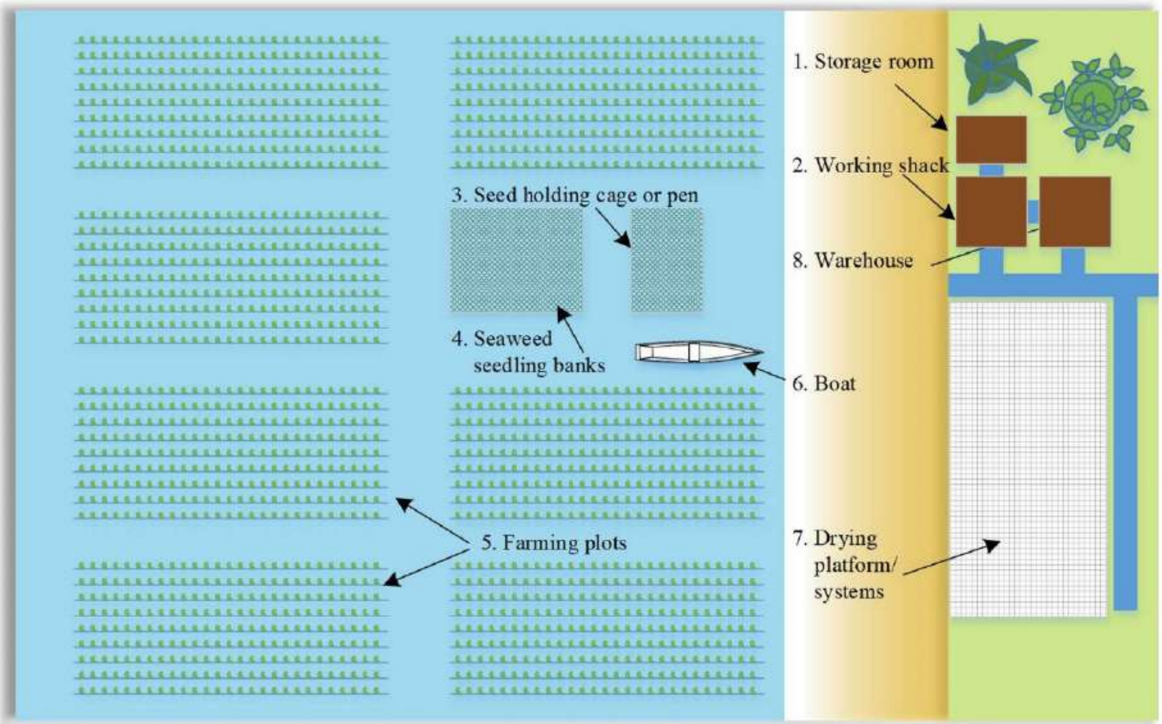


Table 10. Grow- out information for Eucheumatoids

Parameters	Description
Grow-out time (until harvest)	30-45 days (Sometimes up to 60 days)
Tasks at sea during grow-out	Adjusting depths, removing sediments and filamentous algae
Frequency of farm visits	Almost every day
Best season to grow	Throughout the year production, but cooler months are best (24-29°C)
Maximum water temperature	30°C
Biofouling (Epiphytes and epibionts)	Seasonal and regional such as attachment of barnacles and filamentous algae
Pests and diseases	Ice-ice syndrome (seasonally)
Grazers (Natural predators)	Mostly rabbitfish and surgeonfish
Monitoring equipments	Regularly monitoring with portable sensors and record farm activities
Production planning tools	Intuition, tidal cycles, pen and paper

Source: Adapted from Hatch Innovation Services, 2022

13. Common Diseases and Preventive Measures

The incidences of disease and epiphytic infestations are on the rise in recent times which have severely affected biomass production, as well as the yield and product quality of carrageenan. However, efforts in producing/selecting disease-resistant seedlings or commercial extracts to treat seaweed disease have not been commercially viable as yet. Thus farmers must continue to select the appropriate farming methods, suitable sites, seasons and management techniques. Common diseases, practical remedies and prevention techniques are presented in Table 11 and Figure 9.

Table 11. Common diseases, practical remedies and preventive measures

Common diseases	Effect	Practical remedies	Prevention techniques
i) Ice-ice disease: Stresses due to changes in temperature and/or salinity	Loss of colour and consequently, disintegration, and die-off	Remove the affected parts, harvest, or do seedling transfer to other locations	Keep the seaweed in deeper water
ii) Epiphytes: Aquatic marine plants attached to the farmed seaweeds	Competes for space, sunlight, nutrients, and damages seaweed tissues		Choose favourable season
iii) Seasonal grazing: Schools of juvenile rabbitfish appear during in certain seasons	Some fish graze the outer tissue of the seaweed, thus killing it	Evaluate the situation and harvest immediately if needed	Avoid farming during the spawning season of fish grazers
iv) Territorial grazing: Bigger fish	Big chunks of seaweed are bitten off even faster than the seaweed can grow	Trap the fish or scare them away	Exercise care in selecting the farming location
v) Others: Example, mollusc spat attached, domestic wastes and natural contaminants	Makes it prone to infection and disease	Regular cleaning of the seaweed farms	Select another farm site if possible

Figure 9. Illustration of the common diseases and preventive measures (i-iv)

(i) Ice-ice disease

(ii) Epiphytes: *Filamentous algae overgrowing on cultivation lines*

(iii) Herbivorous grazers *such as triggerfish, surgeonfish and rabbitfish bite the tips of Eucheumatoids*

(iv) Others: *Mollusc spat attached to the cultivation lines*

Source: Hatch Innovation Services, 2022

14. Harvesting

The duration of the seaweed culture period is typically 45 days to attain the best growth rate and quality of carrageenan. The seaweed is removed from the lines and all impurities such as plastics, algae, sand and shells which are not acceptable to the buyers and processors, are washed off. On average, the weight of seaweed increases by 5 times during a cycle of 45 days at about 2.5kg/metre of cultivation line. Seaweeds are harvested manually and transported to the land by boat or net. Mechanical harvest methods are not widely available yet. The harvesting parameters and transportation techniques are presented in Table 12 and Figure 10.

Table 12. Harvesting parameters

Parameters	Description
Number of harvests per year	7 (3-10) times depending on the region
Types of harvest (full/partial)	Full
Time of harvest from planting (days)	45 days (30 - 60 days)
Average yield per harvest (wet wt. per m per harvest)	2.5 (2-5) kg/metre/harvest
Average weight increase per cycle (45 days)	5 (3-8) times
Harvesting method	Manual
Transport of harvest to land	Boat, floats or nets at low tide

Source: Adapted from Hatch Innovation Services, 2022

Figure 10. Harvesting and transporting seaweed to the land (i-iv)

i) By net *Photo credit: Hatch Innovation Services, 2022*

ii) By float *Photo credit: VUSTA 2022*

iii) By motor boat *Photo credit: Hatch Innovation Services, 2022*

iv) By wheel mechanism *Photo credit: Hatch Innovation Services, 2022*

15. Post-harvest Handling, Drying and Packing

Post-harvest handling is very important as it affects the quality of the seaweed and thus the quantity and quality of carrageenan. The drying methods for seaweed can be divided into four basic categories: (i) Conventional (e.g., platform, hanging, indoor (shade) and 'sauna'); (ii) Passive (e.g., greenhouse concept, chimney concept); (iii) Active (e.g. freeze dryer, de-humidifier and oven); and (iv) Hybrid (e.g. wind turbine drier, double-pass solar collector with fins). Since the successful cultivation of *Eucheumatoids* began in the early 1970s, the cheaper conventional methods of drying harvested seaweed have remained popular among the majority of farmers. New drying methods are still in the early stages of development and technology transfer to the industry (Ali, *et al.,* 2017). Information on post-harvesting, and a summary of the advantages and disadvantages associated with various drying techniques is presented in Table 13 and Table 14 respectively.

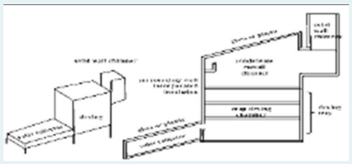
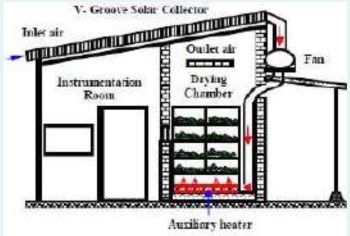
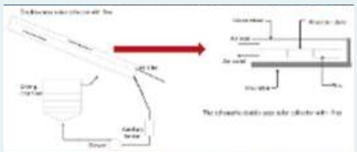
Table 13. Post-harvest information for Eucheumatoids

Parameters	Description
Cleaning and drying	
Cleaning	Check the seaweed and clean by hand; use a pressure washer if needed
Drying method	Sun drying on platforms or by hanging the line up
Duration of drying (in good weather)	2-4 days
Wet-to-dry ratio	7:1
Moisture content after drying	35% - 50%
Treatment of cultivation lines	Sun or shade drying, rubbing, beating
Marketing and quality parameters for dried seaweed	
Point of Sale (POS)	Drying platforms, farmer's house or collective warehouse
Primary buyer	Local collector or trader
Type of transaction	Cash
Type of quality test at POS	Just visual / touch, most of the times based on trust
Other quality parameters	Max. 3% impurities and 1% sand
Unit of sales	50 - 100 kg per nylon sack
Certification	None

Source: Adapted from Hatch Innovation Services, 2022

Table 14. Summary of advantages and disadvantages of the varied drying techniques for Eucheumatoids

Types of drying techniques	Advantages	Disadvantages	Illustration
1. Conventional			
1.1. Hanging	Preserved colour	Large surface area (footprint) required; not hygienic (possible avian contamination); low quality raw dried seaweed (RDS)	
1.2. Platform	Cheap	Large surface area required	
1.3. Shade drying	Quality is maintained	Longer time needed	A kind of sun drying technique using shades to maintain quality.
1.4. 'Sauna-like'	Higher carrageenan yields with improved quality characteristics	Moisture level is maintained	

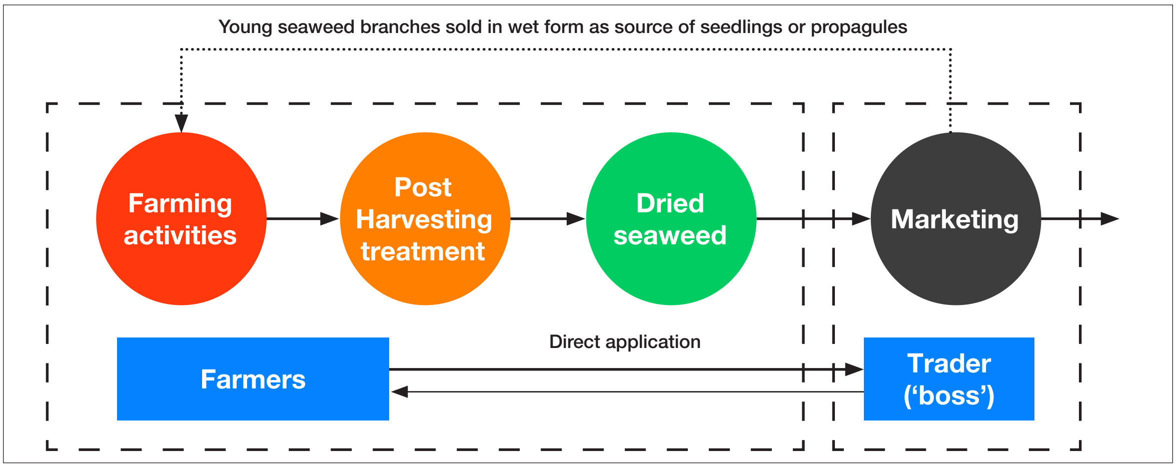
2. Passive			
2.1. Greenhouse concept	Quality is maintained	Daylight operation only	
2.2. Chimney concept	Hygienic product	Longer time required	
3. Active			
3.1. De-humidified air drying	Reduction in the growth of mould	High cost; small capacity	
3.2. Forced- convection dryer with a v-groove collector	Higher temperature needed	High cost	
4. Hybrid			
4.1. Wind turbine & solar dryer	Renewable energy	High maintenance cost	
4.2. Double-pass finned collector	Preserved quality; high temperature needed; high efficiency; economical	High cost; small capacity	
4.3. v-groove hybrid solar drier (v-GHSD)	Efficient management tools needed	Medium cost	

Source: Summarised from Ali, et al., 2017

16. Sales and Marketing

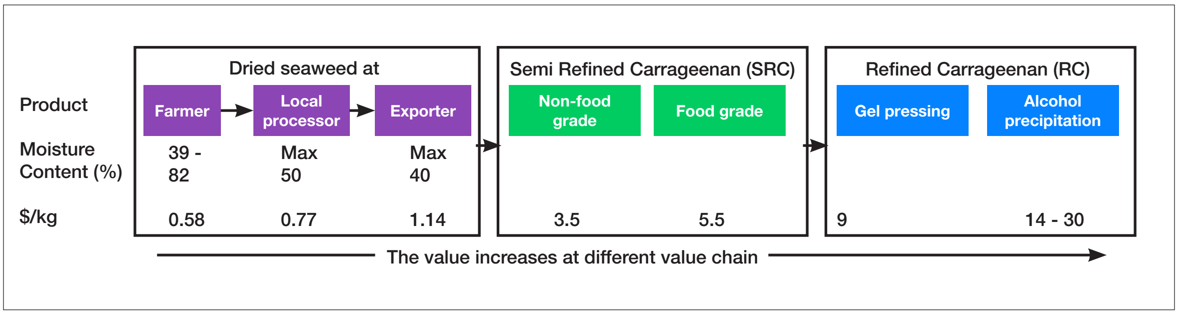
Eucheumatoids are sold in two forms: (i) Dried seaweed used as a raw material in the processing of carrageenan and (ii) Fresh seaweed used as a seedling source. The value chain ends with the carrageenan being exported to the international market (Figure 11). The price of dried seaweed fluctuates according to its quality and demand from the carrageenan industry. An example of the seaweed carrageenan value chain and prices in Malaysia during 2018 is given in Figure 12.

Figure 11. Overview of the seaweed carrageenan value chain and relationship between trader and farmer



Source: Nor, et al., 2020

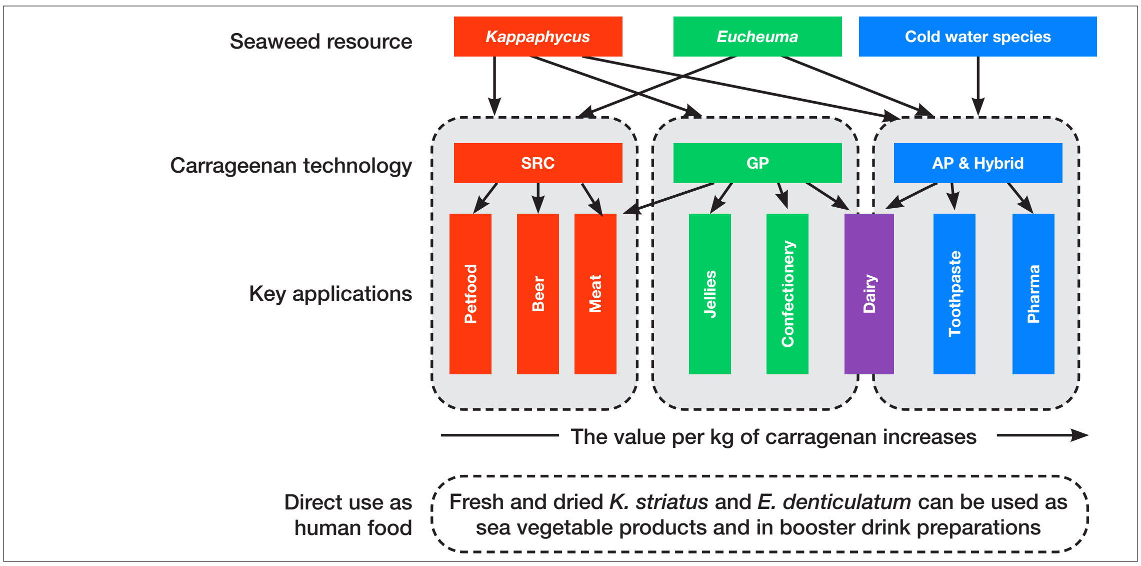
Figure 12. Example of carrageenan seaweed value chain and prices in Malaysia during 2018



Source: Nor, et al., 2020

The carrageenan industry can be divided into three main sectors based on production technology. These sectors are the SRC, GP and AP as well as the mixed sector (Figure 13). The SRC and GP sectors are mainly located in Asia, and is basically linked to raw material supply. The AP and hybrid sectors are located in the West, characterised by a relatively small number of companies serving high-value, niche markets, including toothpastes and pharmaceuticals and the dairy market.

Figure 13. Schematic diagram of the carrageenan industry at present, showing major segmentation by seaweed resource, production technology and key applications



SRC = Semi-refined carrageenan, GP = Gel press, AP = Alcohol precipitation
Source: Cambell and Hotchkiss, 2017

17. Food Safety and Sustainable Seaweed Value Chain Development

Carrageenan is safe to use as a food additive as well as in infant formula. However, there is some controversy about the health food safety of carrageenan above a certain consumption level. Further research and action are needed to address this issue (Neish and Suryanarayan, 2017). Meanwhile, harmonised regional and national legislation on food safety hazards associated with seaweed are generally lacking. Although some private standards have been recently introduced (e.g., by the Aquaculture Stewardship Council/Marine Stewardship Council, and the Norwegian Seaweed Farms), they either do not address food safety directly, or they do not do so in sufficient depth. There is, therefore, a significant regulatory gap concerning food safety in seaweed that requires attention (FAO and WHO, 2022).

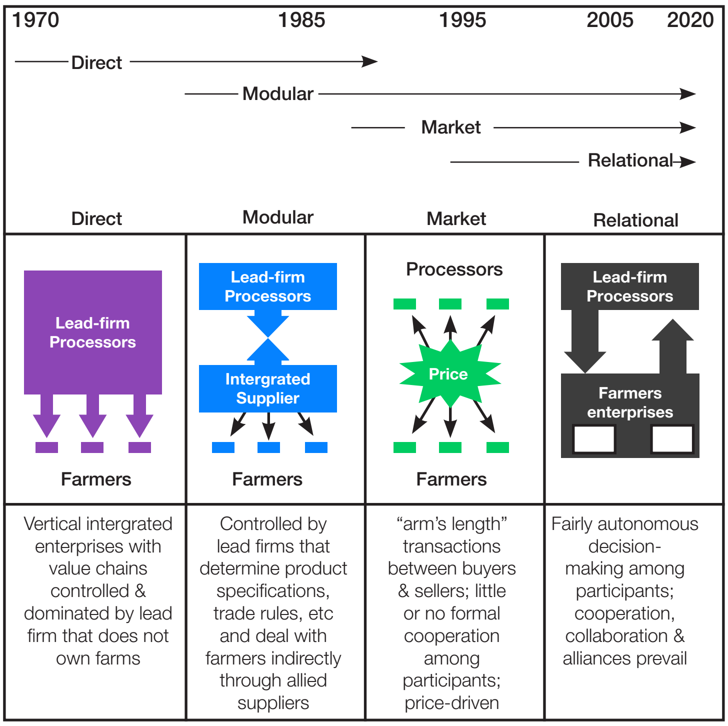
The history of the seaweed (carrageenan) value chain in terms of its governance models from 1974 to the present, is elucidated in Figure 14. Direct governance was typical during the early development of *Eucheumatoid* seaweed farming from early 1970 until the mid-1980s. Farmer linkages were directly to company representatives including trainers, extension workers and staff of company-operated buying stations. However, direct governance value chains did not prove to be sustainable and the evolution has been towards a "relational" mode in order to enhance sustainability.

The second phase of the value chain development occurred from the mid-1980s until the mid-1990s as modular governance substantially displaced direct governance. Processors still determined product specifications and trade rules, but they operated through integrated suppliers.

The third phase of value chain development took place in the mid-1990s when market governance began to replace direct and modular governance. "Long-hand" trading between buyers and sellers became common when large volumes of seaweed were sold under short-term contracts or on the spot market. Market governance tends to be "current" and does not support mechanisms toward sustainability. Therefore, traceability and quality control, and stability of seaweed prices become more difficult to manage.

The fourth stage of value chain has come about due to evolving market pressures for sustainability and fair trade, increasing the need for transparent links from end-to-end and thus stimulating development of relationships. Consolidating farmers into business units such as cooperatives allows them to obtain the critical mass needed to participate in regional and global value chains while linking directly with processors.

Figure 14. Governance models in tropical (carrageenan) seaweed value chains



Modified from Neish, et al., 2017
Valderrama, et al., 2013

18. Challenges and Issues

The cultivation of *Eucheumatoid* seaweed requires a moderate investment but at the same time, it is labour-intensive, and the profit is low. Hence, it is attractive to relatively low-income communities which have other alternative income sources. Not much has changed with regard to the cultivation, harvesting and post-harvest methods in the farming of *Eucheumatoids* since it started about 50 years ago (since the 1970s). The seedling quality has not been improved significantly, and planting and drying methods are still mostly manual. Many challenges have been identified along the value chain, as presented in Table 15.

Table 15. Challenges and issues faced by the seaweed stakeholders and recommendations

Value chain	Challenges and issues	Recommendations
Input/suppliers	Unsuitable aquatic environments (affected by predators e.g., rabbitfish)	Select suitable locations (water quality, biology). Proper coastal planning to avoid conflict with other economic activities
	Unfavourable weather, filamentous algae (seasonal)	Choose favourable seasons
	Lack of space to expand and non-sustainable use of mangrove trees as stakes for lines	Move to offshore areas and use floating systems
	Possible encroachment on to coral reefs	Regulate policies that seaweed farms cannot be located near or on coral reefs or within MPAs
	Lack of quality seedlings, ice-ice syndrome	Have seedlings with high disease resistance (coupled with good yield and carrageenan quality characteristics)
	Vegetative propagation could transmit disease or reduce quality	Propagation using micropropagation or sporophytes
	Poor quality of planting materials	Use of high quality and sustainable floaters, string etc
	Use of non-biodegradable planting material such as the soft plastic tie-tie	Use of bio-degradable planting materials such as cotton ties
Farmers	Labour-intensive and poor seeding/post-harvest handling	Increase productivity through automation from seeding to harvesting
	Lack of drying facilities / space and access to seaweed farming area	External support for drying facilities and infrastructure to access to seaweed farming area
	Monoculture of seaweed	Implement integrated aquaculture which can include several trophic levels of fish, filter feeders and seaweed
	Dependent on natural nutrients in seawater	Supplement nutrients for seaweed in_nutrient-depleted areas
	No Best Aquaculture Practices (BAP) is available for seaweeds.	Develop and adapt Best Aquaculture Practices (BAP) for seaweeds
	Strong price fluctuations and low farm gate price for dried seaweed	Contract farming with processor via trader to ensure stable price and profit
Traders and supported actors	Best Aquaculture Practices (BAP) are not yet recognised	Increase support for, and to be willing to pay better prices for sustainably farmed seaweed
	Weak acceptance by farmers of new cultivation innovations	Organise trainings/workshops/seminars and study visits to successful seaweed farming areas/farmers and promote the sharing of knowledge and best practices
	Weak linkages between and amongst academia/research centres/private sector	Create national and international collaboration and networking to improve scientific knowledge and strong cooperation between public and private sectors
	Lack of financial support to recover after natural risks (e.g. cyclones)	Develop aquaculture insurance to support farmers' recovery
	R&D has stagnated in the carrageenan industry, inadequate knowledge on farming, processing and the role of seaweed in food and other sectors	Establishment of centres of excellence in seaweed agronomy
	Controversy on the health effects of carrageenan	Further study and action are needed to address the issue

Sources: Hatch Innovation Services, 2022, Ginigaddara, et al., 2018 and Hayashi, et al., 2010

There are however, some interesting prospects related to seaweed farming. For example, seaweed plays an important component in regenerative coastal aquaculture, a climate-friendly model where seaweed and/or shellfishes, fishes and crustaceans are grown in a manner so that fresh water, feeds or fertilisers are not required. Seaweed and shellfish can absorb excess nutrients and carbon, and help to reduce harmful algal blooms (HABs) as well as deoxygenated dead zones (Figure 15). They can also be used as food for fish and crustaceans. Regenerative coastal aquaculture has the potential to enhance local food and nutritional security. A regenerative coastal aquaculture model in Singapore that grows seaweed, oysters, and green mussels for lobster and crab food is yielding very positive results Figure 16 (i-vii).

Figure 15. Concept of regenerative coastal aquaculture for human food production

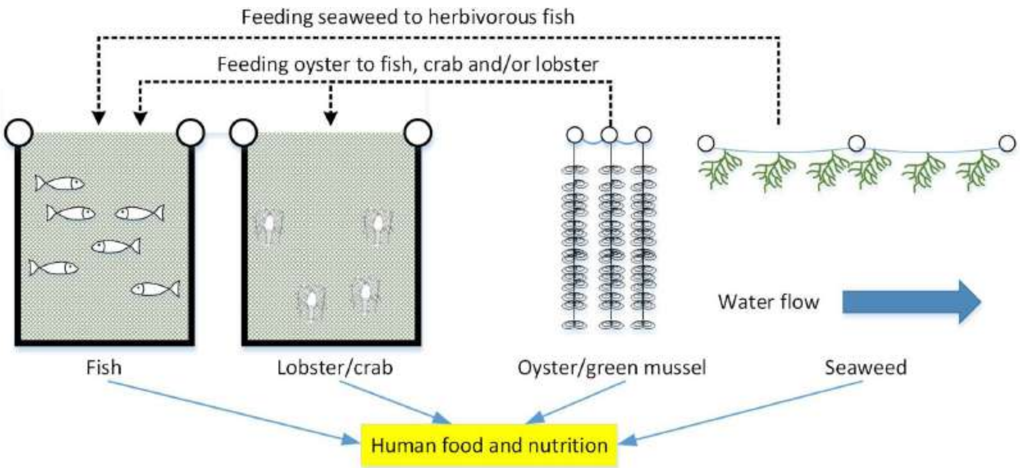


Figure 16. Regenerative coastal aquaculture trial in Singapore (i-vii)

i) Seaweed farming

ii) Green mussel

iii) Oyster

iv) Crab

v) Lobster

vi) Feeding mussels to mud crab

vii) Lobster spawning trial

Photo credit (i-vii): Philip Gu and Dao Huy Giap

19. Roles of Stakeholders and Investors

The roles of stakeholders and investors in seaweed farming can be summarised in Figure 17.

In terms of the farmer or the farmer's family, spouses and relatives share the work and income among themselves. In seaweed farming, men are often responsible for the heavy work such as planting, maintenance and harvesting, while the women and children are responsible for less heavy work like tying the seedlings, drying and sorting dried seaweed. Seaweed farming requires a lot of seasonal labour, so the job-based pay scheme is often used. Workers usually come from the same community and may even be neighbours. Sometimes they work together in a group or for different farmers.

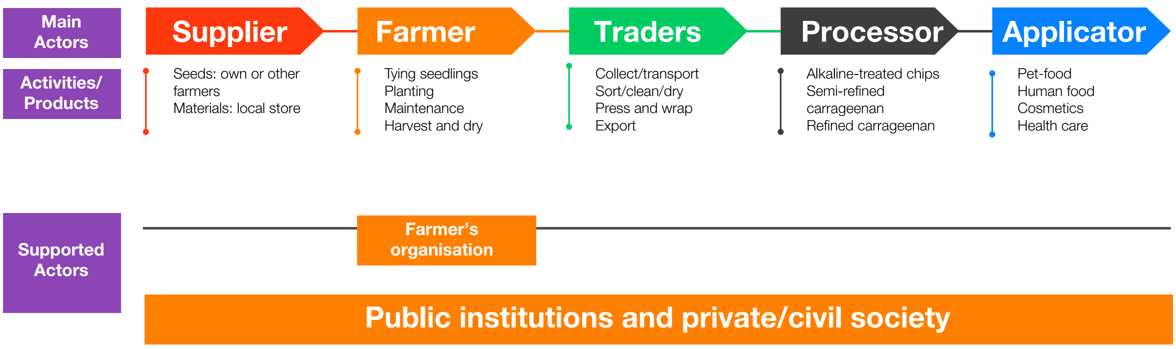
Farmers' organisations are established by the farmers themselves for the purpose of sharing resources in providing inputs, information on cultivation techniques, marketing and selling of the seaweed. The organisation could be an official entities such as cooperatives, associations and cooperative groups, or unofficial such as teams, groups or clubs.

Traders include collectors and exporters. Their function includes (i) Collecting/transporting, (ii) Sorting/cleaning/drying, (iii) Pressing and wrapping, and (iv) Selling or exporting raw dried seaweed to domestic or international processors. Collectors often assist seaweed farmers including buying back products.

Meanwhile, the government, non-government organisations (NGO) and other supported actors' programmes/projects can provide active support directly to farmers through training and equipment initiatives, as well as training on best practices.

All the relevant stakeholders have to play equal and important roles in improving the seaweed value chain market access, investment in innovations, and in promoting the multifaceted benefits of seaweed.

Figure 17. Roles of stakeholders and investors in seaweed farming



20. Cost-Benefit Analysis

Two common *Kappaphycus* farming methods are used for cost-benefit analysis. They are the floating bamboo raft and fixed off-bottom plot. For a family of three persons, a suitable size for a seaweed farm may consist of a 8100 m cultivation line and 135 floating bamboo rafts or 15 fixed off-bottom plots.

Taking the example of the floating bamboo raft: its size is 3.0 m x 3.0 m and consists of four main bamboo poles (3.6 m each) which are tied together by four diagonal bamboo slats (1.2 m each) in a square shape. A fishing net is attached underneath to prevent fish grazing. In each raft, there are 20 three-metre cultivation lines, each line carrying 20 seedlings weighing about 200 g/seed. The rafts are anchored at the farming site by iron anchors (20 kg), and with each anchor holding a cluster of five rafts.

The fixed off-bottom plot (30 m × 20 m) is made of casuarina and bamboo poles, and a polypropylene rope securely tied to the stakes at a distance of 0.5m from the bottom. Approximately 200g of seed is inserted into a loop with a seed spacing of 20 cm in a 30 m PP (3 mm) rope and line space of 1.0 m. The length of the total cultivation line is about 540 m for each plot.

The economic analysis for the two *K. alvarezii* farming models are presented in Table 16 and Table 17 respectively.

Table 16. Economic analysis (in USD) for two K . alvarezii farming models

Items	Unit	Total cost for 135 rafts	Total cost for 15 plots
A. Production parameters			
1. Total length of lines	m	8 100	8 100
2. Size of farming plot	sqm	1 750	9 000
3. Number of cycles per year	cycle	6	6
4. Length of a cycle	days	45	45
5. Annual yield of dry seaweed	kg	21166	18 049
6. Annual productivity	kg/m/year	2.61	2.23
7. Cycle productivity	kg/m/cycle	0.44	0.37
8. Farmgate price	USD/kg	0.34	0.34
B. Gross revenue	USD/year	7 244	6 177
C. Total annual cost	USD/year	2 300	1 853
D. Economic analysis			
1. Net return (B-C)	USD/year	4 944	4 324
2. Cost of production (C/A.5)	USD/kg	0.11	0.10
3. Return on investment (D1/C)	%	215	233
4. Infrastructure cost per m of cultivation line	USD/m	0.46	0.33

Note: 1 raft 3 x 3 m, 60 m cultivation line; 1 fixed off-bottom plot of 20 x 30 m, 540 m cultivation line.
Source: Shanmugam, et al., 2017

Table 17. Comparison of investment costs (in USD) for floating bamboo raft and off-bottom monoline culture plot

Items	Total cost for 135 rafts			Total cost for 15 plots		
	Total investment	Economic life (years)	Annual cost	Total investment	Economic life (years)	Annual cost
Grand total of infrastructure and operational costs (A + B)	5 132		2 300	3 521		1 766
A. Infrastructure	3 701		1 120	2 236		733
HDPE fishing net	1 247	3	416	1 386	3	462
1.5 mm HDPE rope	106	3	35	12	3	4
3 mm PP rope	319	3	106	213	3	71
5 mm PP rope	277	3	92	-	-	-
6 mm PP rope	65	3	22	-	-	-
10 mm PP rope	34	3	11	190	3	63
12 ft. bamboo	887	3	296	-	-	-
Iron anchor (20 kg)	185	3	62	-	-	-
Anchors (50 kg each)	-	-	-	41	3	14
Anchors (25 kg each)	-	-	-	205	3	68
Floats	-	-	-	89	3	30
Seed cost	488	10	49	488	10	49
Transportation cost	92	3	31	46	3	15
Cost per metre of culture line	0.46	-	-	0.28	-	-
B. Operational costs	1 431	-	1 180	1 285	-	1 034
Storage (10 m × 5 m)	171	3	57	171	3	57
Cost of drying bed (300m2)	205	3	68	205	3	68
Cost of boat / catamaran	684	1	684	684	1	684
Maintenance	370	1	370	224	1	224

Source: Shanmugam, et al., 2017

The infrastructure cost per metre of the culture line in a floating bamboo raft is 0.46 USD/m and 0.33 USD/m for the fixed off-bottom plot. Although the investment for the fixed off-bottom plot is lower, it is difficult to find a good location for this method and the farmer might lose the crop during rough weather. On the other hand, floating bamboo rafts can be utilised in shallow or deep waters. Farmers can move the floating rafts when needed to protect the seaweed from rough weather. The return on investment for both the systems is higher than 200%, which is enough for the seaweed business to be considered as sustainable.

21. Conclusion

In general, marine plants such as cultivated seaweeds will continue to sequester more carbon dioxide (CO_2) than terrestrial plants from the atmosphere (even if the capture is only for a relatively short period of time) through their growth and processing cycles. Seaweed forests and enhanced future farming practices will help to mitigate global warming besides producing more food for people and feed for animals. The cultivation of *Eucheumatoid* seaweed is labour-intensive and low profit; therefore modifications of farming techniques and the integration of a certain level of mechanisation is especially required. Seed production for *Eucheumatoids* is generally through vegetative propagation via cutting although micropropagation techniques have been piloted. Seaweed is still susceptible to some diseases like ice-ice disease and epiphytic as well as endophytic “infections”. It is clear that the success of *Eucheumatoid* cultivation depends on effective collaboration among the relative stakeholders along the seaweed value chains as well as a coherent integration of culture systems, while making quality seed available and ensuring governance and long-term investment.

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