SEAWEED FARMING TECHNOLOGIES

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Introduction

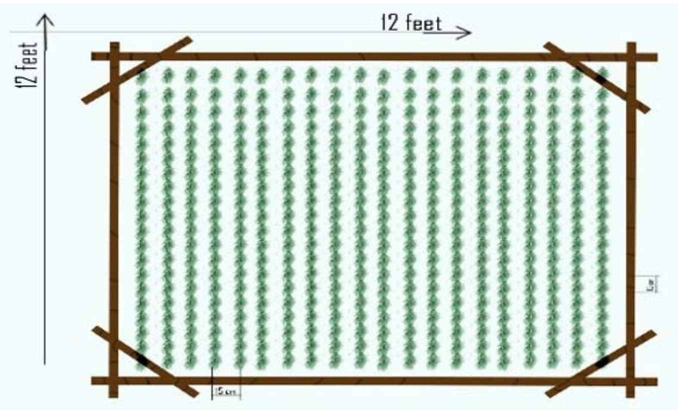
Seaweed farming is a climate-resilient aquaculture practice. This cultivation does not need land, freshwater and fertilizers. It is a sustainable, diversified livelihood option for coastal communities. It reduces the effects of oceanic eutrophication and acidification and oxygenates the seawater for a healthy ecosystem. Seaweeds are valued commercially for their cell wall polysaccharides, such as agar, algin, carrageenan etc. and for their bioactive metabolites, manure and fodder. They have a variety of commercial applications in the food, pharmaceutical, cosmetics and mining industries. Some seaweeds are also gaining importance as healthy food for human consumption. World seaweed production was 35.1 million tonnes of wet weight with the first sale value estimated at 16.5 billion USD (FAO, 2022). In India, nearly 47,000 tonnes wet weight of seaweeds are being harvested from natural seaweed beds (species of *Sargassum*, *Turbinaria*, *Gracilaria* and *Gelidiella* by nearly 5,000 families in Tamil Nadu) (FRAD, CMFRI, 2023). In India, seaweed farming is being carried out with *Kappaphycus alvarezii*. It is one of the economically important red algae, which yields carrageenan, a commercially important polysaccharide. Carrageenan is used in a variety of commercial applications as gelling, thickening, and stabilizing agent, especially in food products such as frozen desserts, chocolate milk, cottage cheese, whipped cream, instant products, yoghurt, jellies, pet foods, and sauces. Aside from these functions, carrageenan is also used in pharmaceutical formulations, cosmetics, and industrial applications such as mining. Farming of *Kappaphycus alvarezii* by the fisherfolk of the Tamil Nadu coast touched the highest yield of 1,500 tonnes of dry weight in 2012-13. However, production sharply declined after 2013 due to mass mortality. Around 400-500 tonnes of dry weight per year is being produced. More than 2000 families are involved in seaweed farming on the Tamil Nadu coast.

Seaweed farming

Bamboo rafts and the monoline method of seaweed farming are being predominantly adopted on the Tamil Nadu coast of India. In calm and shallow places, the floating bamboo raft method (12 × 12 feet bamboo poles) is ideal. In places characterized by moderate wave action, shallow depth and less herbivorous fishes, the monoline method of seaweed farming is ideal. The tube net method is being adopted in places with higher wave actions.

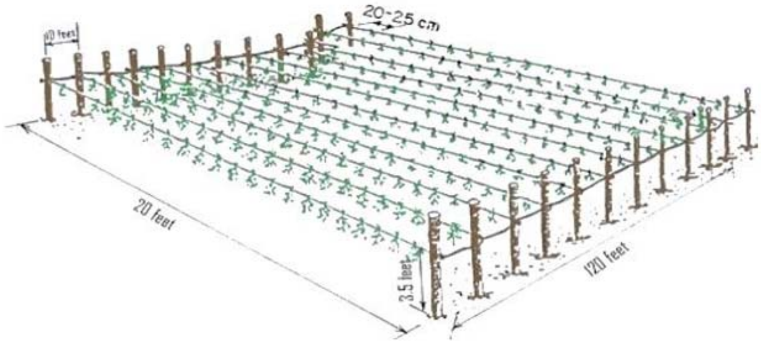
Bamboo raft method

Hollow bamboo poles of 3-4" diameter for a 12′x 12′ (3.6x3.6m) main frame and 4′ x 4′ (1.2x1.2m) for diagonals without any natural holes, cracks etc., have to be selected and tied using 4mm rope. Plantation ropes for seeding can be made by cutting 3 mm or 3.5 mm polypropylene twisted rope into 20 bits of 4.0 - 4.5 m length each. 400 pieces of HDPE braider each with 25 cm length can be made by cutting the lengthy braider into 20 pieces for 20 plantation ropes. Twining of 20 braiders is to be done, each on the 4.5m length polypropylene twisted plantation rope at 15 cm intervals leaving 0.5m on either side for tying on the pole. Seedlings should be taken from healthy, preferably from the young portion of the plant with more apical portions. If seedlings are taken from other districts/states, they should be placed in a clean net bag and kept at the bottom (1-2m depth) of the sea for a few days before planting. Seed material should not be placed in open areas which are exposed to direct sunlight, rain, temperature and humidity changes. This would greatly affect the quality of seed material. Around 150 – 200 grams of seaweed fragments are tied at a spacing of 15 cm along the length of the rope. A total of 20 seaweed fragments are tied in a single rope and 20 such ropes are tied in a raft with a seed requirement of 60–80 kg. A cluster of five rafts linked with 6mm rope. A cluster of five rafts is positioned in the near shore area of 1.0 to 1.5 m depth using a 30 kg anchor tied with 12-14 mm rope. In one hectare of area, 400 rafts of 12 x 12 feet size raft are ideal for seaweed farming. This ensures enough space between the rafts for good seawater circulation, maintenance and other farm operations.



Monoline method

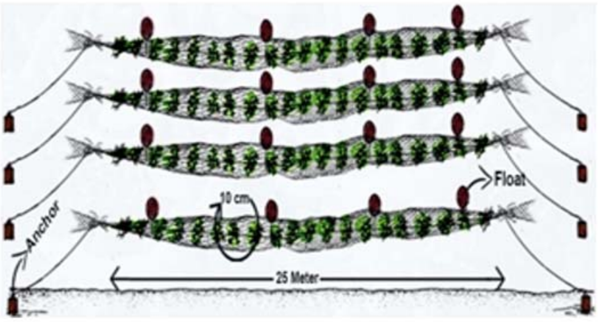
Based on the location, the dimensions of the monoline units will vary. The method followed in Ramanathapuram district of Tamil Nadu is depicted below: The required number of casuarina/eucalyptus poles of 3-4" diameter and 10 feet length without any natural holes, cracks, etc., are to be selected. For one unit, four casuarina poles of 10 feet length and 3-4" diameter are erected at 10 × 20 feet distance, each in the corner. On two sides, a 6mm rope is tied, on which the seaweed seedling rope is tied. Around 150 – 200 grams of seaweed fragments are tied at a spacing of 15 cm along the length of the rope (6.75m). A total of 40 seaweed fragments are tied in a single rope. The total seed requirement per monoline unit is 60 – 80 kg. Floats are tied on each rope to increase the buoyancy. One segment (120 feet in length and 20 feet in breadth) constitutes 10 monoline units (one monoline unit is equivalent to one raft in terms of



production). Parallel orientation of monoline to water movement or shoreline will avoid damage to seaweeds, and casuarina poles and minimize the attachment of floating debris.

Tube-net method

Using HDPE food grade nets (1.5cm mesh size), tube nets can be made to a length of 25m with 10cm diameter. The tube nets are held floating in the water column below the surface with an appropriate number and size of floats at regular intervals. Anchor stones (about 30 kg) are used at each end to hold the tube nets steady in the water column; if required, additional anchors of appropriate size and weight can be fixed in between. The seed material of 15 kg fresh weight is loaded into the tubes with the aid of a 1.0 - 1.5 m long plastic pipe acting as a funnel or a hopper (four tube nets are equivalent to one raft in terms of production). The pipe diameter should be a little less than that of the tube net for efficient seeding. The plastic pipe is inserted into the tube net and the entire tube is pulled down so that the mouth of the plastic pipe stands out of the tube. The tube net is pulled down from the bottom of the plastic pipe carefully, in such a way that seedling material gets loaded into the tube sequentially leaving no gap between the seedlings. This process is continued till the entire tube net is seeded with algal biomass. The tube nets are closed at both ends with rope to prevent material from being lost. Seaweed farming using the High-Density Poly Ethylene (HDPE) raft-based tube net method in rough sea conditions was successfully demonstrated by ICAR-CMFRI.



Maintenance

- Seaweeds need gentle care.
- Daily visit to the farm is necessary.
- Broken-off lost seedlings can be replaced periodically.
- Other seaweeds, sediments attached to the plants and ropes have to be removed regularly.
- Broken and drifted plants have to be removed periodically from the farming site.
- Damaged bamboo/casuarina poles have to be replaced periodically.

- After 1 to 2 years of the culture period, the unusable bamboo poles, ropes, braiders, and nets have to be disposed of properly instead of leaving them in the sea/shore.

Management of disease

- "Ice-ice" is the only disease reported in seaweed farming. It is caused probably due to abiotic stress like low salinity, high temperature and low light intensity.
- The branches will show the symptoms of whitening and eventually disintegrate which may result in crop loss.
- If the disease is observed, the entire crop has to be harvested and farming has to be restarted with new seedlings.

Management of epiphytes

- Attachment of undesirable seaweeds to the cultured species, which usually occurs at the onset of monsoon brought by the change in water temperature, trade wind and water current is epiphytism.

- Drifted seaweeds compete for space, nutrients and sunlight with the cultured species. Other seaweeds attached to the cultured species have to be removed periodically.

Management during Natural Calamities

- Natural calamities like a heavy storm and cyclone causes complete damage to *K. alvarezii* farms.
- Based on early weather warnings, premature harvest can be done.
- A portion of seaweed seeds can be placed in a net bag and kept in deeper waters for further use

Harvest and economics

The crop duration for *Kappaphycus* farming is 45-60 days. In a year, four to six crops or cycles (6 to 9 months) can be harvested depending upon the climatic condition. Seeding of 150g grows to 500 to 1000g in 45 days. Drying the harvested seaweeds on sand should be avoided to reduce contamination. Harvested seaweeds have to be dried on elevated drying platforms. While drying, impurities like stones, shells and other foreign matter can be cleaned. Harvested and dried seaweeds have to be covered with tarpaulin sheets during rainy seasons. After seaweeds are dried, they can be packed in sacks and stored in a clean dry place. Seaweeds either in dry or wet forms are transported to the industries for commercial. The average dry weight percentage of the harvested seaweed is 10 per cent. Farmers currently receive Rs. 16/- to Rs. 18/- and Rs. 80/- to Rs.110/- per kg for fresh and dried seaweed, respectively. The economics of *Kappaphycus alvarezii* farming, as analysed by ICAR-CMFRI, is as follows:

No.	Components	Details/Cost
1.	Seaweed production: 1,000 kg/raft/year minus 240 kg, which is used as seed material for 4 crops/year	760 kg (wet weight)
2.	Average Price of dried seaweed	Rs. 95/ kg/dry weight (Dry weight = 10% i.e., 76/-per kg)
3.	Total revenue generated	Rs. 7,220/year/ raft @ Rs. 95/kg/dry weight
4.	Total cost of production (including capital cost)	Rs. 2,500/raft/year
5.	Net revenue	Rs. 4,720/raft/year (Rs. 7,220 minus Rs. 2,500)
6.	**Total Net revenue (45 rafts*) in dry weight**	**45 x Rs 4,720 = Rs. 2,12,400/year**
7.	**Net revenue from one hectare (400 rafts) in dry weight**	**Rs. 18,88,000/year**

**A person can handle an average of 45 rafts (12 ft x 12 ft)*

Economics of *Gracilaria* farming

The seaweed farming trials by the ICAR-CMFRI in various islands of Lakshadweep since August 2020 under the ICAR-sponsored National Innovations in Climate Resilient Agriculture (NICRA) revealed a promising daily growth rate for the indigenous red algae *Gracilaria edulis*. The experiments focused on farming using PVC net cages, PVC rafts and bamboo rafts. Commercial farming is being attempted by private companies through community participation.

Carbon sequestration potential of farmed seaweed (*Kappaphycus alvarezii*)

The specific growth rate of the seaweed multiplied by % composition of carbon (C) and 3.667 (mass of CO_2= 44/ mass of C= 12) gives an estimate of the specific rate of sequestration (per unit mass of seaweed per unit time) of carbon dioxide by the seaweed. The specific rate of sequestration of CO_2 per gram dry weight of seaweed is 0.018673 g day^{-1} (0.02557 /* 0.19915 /* 3.667). The specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 19 kg CO_2/day/tonne dry weight of *K. alvarezii* (= 760 kg CO_2/day/tonne dry weight/ha).

Integrated Multi-Trophic Aquaculture (IMTA)

Intense fishing pressure along the coastal waters, coupled with the negative impacts of climate change, has lately started impacting the livelihoods of fishers. While harvests are dwindling, the demand for marine fish is increasing steadily owing to its crucial role in ensuring the food and nutritional security of the population. This necessitates augmenting marine fish production through farming promising commercial fish species in the sea. Realizing this important priority, the ICAR-CMFRI has developed and standardized the technologies for seed production and farming of marine finfish and shellfish in open sea cages. One of the anticipated issues while expanding sea cage farming is the increased organic and inorganic load in the water and consequent disease problems. In this context, bio-mitigation and increased biomass production can be achieved by integrating different groups of commercially important aquatic species with varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA), which has been gaining global importance in recent times. The ICAR-CMFRI has successfully conducted trials and demonstrated the IMTA by integrating seaweed with sea cage farming of marine finfishes/shellfishes in Tamil Nadu, Gujarat and Andhra Pradesh. This has resulted in increased production of seaweeds, which has improved farmers' livelihoods and contributed to the country's carbon credit.

The ICAR-CMFRI has been promoting cage farming of cobia, a high-value marine fish, since 2010. To achieve environmental sustainability and economic stability, an innovative idea of integration of seaweed with sea cage farming of cobia was demonstrated during 2014-17 at Munaikadu, Palk Bay, Tamil Nadu. A total of 16 bamboo rafts (12× 12 feet) with 60 kg of seaweed per raft were integrated for 4 cycles (45 days/ cycle) along with one of the cobia farming cages. The rafts were placed 15 feet away from the cage in a semi-circular manner to enable the Seaweed to absorb the dissolved inorganic and organic nutrient wastes that move along the water current from the cage.

Currently, through IMTA, seaweed rafts integrated with cobia farming cages had a better average yield of 390 kg per raft, while in the non-integrated raft, the yield was 250 kg per raft. An additional yield of 140 kg of seaweed per raft (56% additional yield) was achieved through the integration with the cage farming of cobia. An additional net income of Rs. 85,120/- was realized through the integration of seaweed rafts with cobia cages.

Carbon dioxide sequestration (per unit mass of seaweed /day/16 rafts/4 crops) into the cultivated seaweed in the integrated and non-integrated rafts was = 47.4 kg CO_2/day/tonne dry weight of *K. alvarezii* vs 30.4 kg CO_2/day/tonne dry weight. Hence, an additional 17.0 kg CO_2/day/tonne dry weight credit was achieved by integrating 16 seaweed rafts (4 cycles) with one cobia farming cage (per crop).

In one hectare of area, a total of 20 cages of 6 m diameters can be integrated with 320 bamboo rafts (12× 12 feet) @ 16 bamboo rafts per cage. IMTA is an eco friendly option that ensures sustainable income to the coastal fishers. It is also one of the significant mitigating measures for reducing the adverse impact of climate change and earns our country carbon credit.

Marine spatial plans

Given the emerging importance of seaweed mariculture, an all-India preliminary survey for the selection of sites suitable for seaweed farming was conducted by ICAR-CMFRI using around 15 parameters along all maritime states of India. The ICAR-Central Marine Fisheries Research Institute (CMFRI) has identified 24,251.9 hectares of potential seaweed farming area (spatial map of 333 locations with geo-coordinates along the Indian coast within 1000 m distance from the lowest low tide line) through coastal surveys and remote sensing data analysis (Johnson *et al.,* 2020: Johnson *et al.,* 2023). Out of 333 sites, trial farming activities are carried out in 78 sites. These sites can yield a maximum of 9.7 million metric tonnes of seaweed (wet weight) annually, facilitating the imminent expansion and effective adoption of seaweed farming in the country. The ICAR-CMFRI has also brought out the "Decision support spatial suitability map for Seaweed Farming in India" (Divu, *et al.,* 2021).

Gaps

- Inadequate availability of good quality seed/plantlets and need for development of improved strains.
- Need for leasing policy of coastal areas in coastal states.
- Technical know-how on the offshore culture of seaweed is yet to be developed in India.
- Poorly organised markets for seaweeds and its products.
- Requirement for diversification of seaweed-based products' value chain and development of processing/products/fodder replacement industries.
- Need for insurance to cover risks associated with farming activities.
- Lack of domestic acceptance of seaweeds as food.
- Need for commercial micropropagation hubs in different parts of the nation for round-the-year seed availability.

Way forward

- Pilot farming trials in potential areas identified suitable for seaweed culture.
- Eco-friendly materials for replacement of bamboo and wooden rafts.
- Exploring scope for exotic strains such as *Eucheuma spinosum* and Higher Agar yielding *Gracilaria* species/ screening for suitable indigenous species which are fast growing and abiotic stress tolerant.
- Genetic improvement of native species for faster growth and better yield of phycocolloids.
- Offshore farming & scientific interventions to minimize grazing, fouling and disease incidences in a collaborative mode.
- Development of culture practices & Large-scale cultivation of native species suitable for fodder replacement/ bio-stimulant.
- Need to create public-private partnerships between the Research Institutions and the industry to set up seed production centres leveraging the micropropagation and other latest technologies.
- Development of seed banks/ micropropagation for continuous round the year production of seeds.
- Exploring the scope for introducing fish farmer producer companies in seaweed farming.
- To develop a rural enterprise comprising of farming, marketing and post-production activities associated with seaweeds - "seaweed hubs" in coastal states.
- Enhancing the availability of credit, insurance (to treat seaweed farming on par with agriculture) and other logistical support for farmers.
- Development of FSSAI standards for seaweed products/recipes (including dried products) for human consumption.
- Govt approval to ensure greater policy support.