Seaweed Farming for Income Generation and Empowerment of Coastal Rural Community

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Seaweeds are macroalgae which are found attached to substratum in benthic habitats. They are multicellular autotrophic photosynthetic plants contributing significantly to the primary production of the marine ecosystem. They are non-flowering plants without true roots, stems, leaves and attached to substratum by means of holdfast. They are a significant feature of most shorelines and shallow water environments throughout the world (Robin South, 1993). They can be found mainly in intertidal and in the sub-tidal region up to a depth, where 0.01 % photosynthetic light is available (Domettila *et al.*, 2013). They have an ecological role of providing habitat and substrata for invertebrates, fish, mammals, and birds (Vásquez 1992; Graham *et al.*, 2007) and a source of food for many grazing vertebrates and invertebrates.

Seaweeds are classified into three broad groups based on their depending on their nutrient and chemical composition to Rhodophyceae (Red algae), Cholorophyceae (Green algae) and Pheaophyceae (Brown algae) (Darcy-Vrillon, 1993). Red seaweeds are found in the intertidal zone, green seaweeds in the shallow intertidal zone and brown seaweeds mostly in the mid intertidal to shallow/ mid subtidal zone. Seaweeds range from giant kelp (20 m long) which are brown seaweed to smaller red and green seaweeds. The global diversity of seaweeds consists of about 6000 species of red seaweeds, 2000 species of brown seaweeds and 1200 species of green seaweeds (Kaliaperumal, 2007), of which 210 species are commercially important and 65 % of which are used as human food (Zemke-White and Ohno, 1999). The seaweed species diversity occurs maximum in the temperate regions of the world, especially Japan and southern Australia.

Uses of seaweeds

Seaweeds are rich in minerals, trace elements, protein, iodine, bromine, vitamins and many bioactive substances. Seaweeds were used as a source of food as early during the fourth century in Japan and sixth century in China. Seaweeds are the only source of marine polysaccharides known as phycocolloids such as agar, carrageenan and algin. Agar is polysaccharide obtained from cellwall of certain members of red seaweeds (Rhodophyceae) like Gelidiaceae, Gelidiellaceae and Gracilariaceae. Carrageenan is obtained from red seaweeds belong to Gigartinaceae, Soliriaceae and Hypneaceae. Algin is membrane mucilage obtained from some brown seaweeds (Phaeophyceae) like Laminaria, Macrocystis, Turbinaria and Sargassum. These phycocolloids find application in various industries as gelling, stabilizing and thickening agents in food, confectionery, textiles, pharmaceuticals, dairy and paper industry. The use of these phycocolloids can be traced back to 17th century in Japan when agar was extracted with hot water.

Seaweeds have also been used as animal feed, as manure and as a source of enzymes, dyes, drugs, minerals and vitamins (Chapman, 1970; Deve *et al*., 1977; Anon., 1987; Joseph and Lipton, 2004). Many protein rich edible red, green and brown seaweeds are consumed in the form of soup, salad, vegetable and porridge. Seaweeds can also be used in fish feeds to supplement minerals and trace elements. Seaweed manure is used in coastal areas for meeting the nutritional deficiencies of plantations. Seaweeds are also used as fodder to feed livestock in many countries. Liquid seaweed fertilizer (LSF) extracted from seaweeds has shown to increase the growth rate of vegetables, fruits and horticultural plants. LSF were found to promote productivity than chemical fertilizers (Bokil *et al*., 1972). Seaweeds are used in treatment of wastewater contaminated with heavy metals like zinc and cadmium. They are also used in effluent treatment in fish and shell farms before being discharged to other water resources. Seaweeds can also be used in multitrophic aquaculture in cages thus reducing the effects of pollution to the aquatic environment and an increase in total output. Seaweed farming will also help in mitigating the negative effects of climate change while protecting the marine ecosystems from ocean acidification and ocean deoxygenation.

Global scenario

Globally, people are shifting toward plant-based food products and vegan diets. Seaweed have amino acid profile similar to that of eggs and can be considered as a great alternative source that is ideal for vegans and vegetarians. As per FAO (2021), 8.8 lakh tonnes (t) (wet weight) of seaweeds were harvested from the wild during 2019, of which Chile accounted for 45% of production. During 2019, 34.6 million t of seaweeds were produced from aquaculture globally and China topped with 58% of production. Among the aquaculture of seaweeds, red seaweed with a production of 18.2 mt was produced in highest quantity. The main red seaweeds farmed are Japanese kelp (*Laminaria japonica*), Gracilaria seaweeds (*Gracilaria* spp.) and nori nori (*Porphyra* spp.).

In general, the following five kinds of seaweeds accounted for more than 95% of world's seaweed culture production in 2019. *Laminaria* and *Saccharina* accounted for 34.65% of the global cultivation for human consumption, mainly as salads, condiments, and sauces. Carageen from tropical algae *Kappaphycus* and *Eucheuma* accounted for 32.62% and was mostly used for carrageenan extraction. *Gracilaria, Porphyra,* and *Undaria* accounted for 10.32%, 8.33%, and 7.16%, respectively. In Asia and South Africa countries, seaweeds (such as brown algae, leafy algae, and kelp) are often used as fish feed like *Laminaria* and *Sargassum* in China, *Kappaphycus* are used as seaweed fertilizer in India, and made into livestock feed in most European countries (Zhang *et al.*, 2022).

Indian Scenario

India with a coastline of about 7516 km supports luxuriant growth of seaweeds along the south east coast of India, Gujarat coast, Lakshadweep Island and the Andaman and Nicobar group of Islands. Out of the 271 genera and 1153 species of marine algae in Indian waters (Subba Rao and Mantri, 2006), seaweed diversity consists of 434 species of red seaweeds, 194 species of brown seaweeds and 216 species of green seaweed (CMFRI, 1987) and a resource assessment in various studies from 91339 tons (fresh weight) (Kaliaperumal, 2000), 260876 tons (wet weight) (Kaladharan and Reeta, 2003) to 6,77,308.87-6,82,758.87 tons (fresh weight) along the Indian coast, while the world natural resources were estimated to be over 20 million tons (fresh weight) (Subba Rao and Mantri, 2006).

India presently harvests only about 22,000 tons of macro-algae annually compared to a potential harvest of 1 005 000 t (Modayil, 2004). In India, nearly 20,000 tonnes wet weight of seaweeds per year are being harvested from the natural seaweed beds (species of *Sargassum, Turbinaria, Gracilaria* and *Gelidiella* by nearly 5,000 families) (Johnson *et al*., 2020) in Palk Bay and Gulf of Mannar regions of Tamil Nadu. The present production of seaweeds from farming in India is about 5200 tones which is mostly from the farming of *K. alvarezii* mainly by bamboo raft method and monoline method. In terms of dry seaweed production, around 400-500 t was produced, which had reached an ever time high of 1500 t in 2012-13.

Opportunity in seaweed farming for coastal communities

The Indian requirement of agar, alginate yearly is about 400 t, 1000 t and 1500-2000 t respectively. The majority of this demand for these phycocolloids is met through imports. The total annual seaweed requirement in dry weight basis is 4,000 t of agar yielding algae; 5,000 t of alginate yielding algae and 4500-6000 t of carrageenan yielding algae (Johnson and Ignatius, 2021). With the increase in demand for seaweed material for various applications, collections from the wild are not sufficient enough to meet the requirement. The culture of commercially important seaweeds through vegetative method of propagation is now the major means for supply of raw material to seaweed-based industries. This provides the coastal communities with the opportunity for utilizing the potential of seaweed farming.

The coastal communities mostly depend upon fishing for their conventional economic activity, which is depleting day by day due to increased fishing pressure. Seaweed farming can be a sustainable alternate livelihood option for woman and rural employed youth among coastal community. Seaweed farming can generate substantial income and extensive employment opportunities in coastal communities (Krishnan & Kumar, 2010) With a view to enhancing production and productivity in the seaweed aquaculture in our country for harnessing the potential of the coastal waters and reduce reliance on wild harvest, Rs 640 crore has been under Pradhan Mantri Matysa Sampada Yojana. These will also promote seaweed cultivation as a viable and sustainable livelihood among coastal rural communities.

Seaweed farming methods

Seaweed cultivation started long back in Hiroshima Bay and Tokyo Bay as early as 16th Century (Imai, 1982). The farming of tropical seaweeds, *Kappaphycus alvarezii* and *Eucheuma denticulatum* started in Philippines during the late 1960's. With a view towards developing suitable technologies for seaweed mariculture in India, experimental cultivation of commercially important seaweeds were undertaken and methods demonstrated.

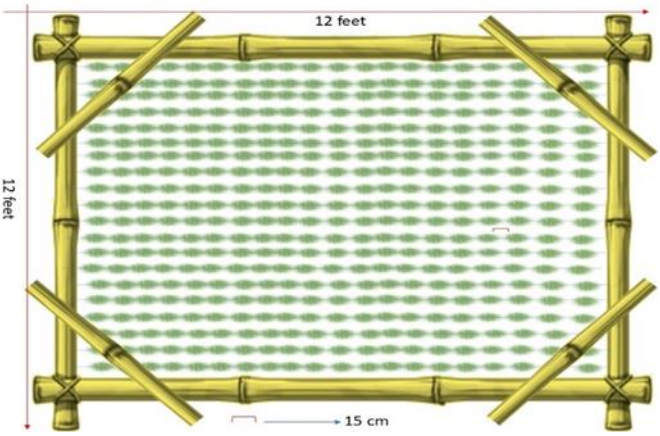
Commercial level cultivation in India started with the transfer of technology of *Kappaphycus* cultivation by CSMCRI to PepsiCo for farming Mandapam area of Tamil Nadu. Corporates backed by institutional and financial support led to the expansion of seaweed (*Kappaphycus alvarezii*) farming through Self Help Groups (SHG) model (mostly women), starting in a small scale in Ramanathapuram District of Tamilnadu in 2000, which had spread to neighbouring coastal districts like Tuticorin, Pudukottai and Thanjavur (Krishnan and Kumar, 2009). Presently in India, commercial level farming of *Kappaphycus alvarezii* is mainly concentrated in Mandapam region of Tamil Nadu and around 1000 families of fishers are involved in farming.

Farming Techniques – *Kappaphycus alvarezii*

Kappaphycus farming is widely carried out by floating bamboo raft, longline or monoline and tube net methods.

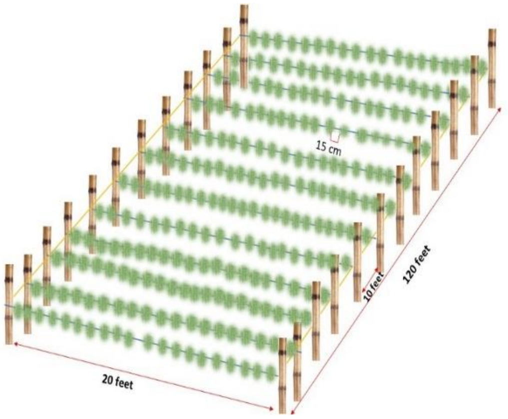
Floating Bamboo raft method

Floating bamboo raft method is ideal in locations which are calm and shallow. Floating rafts are made up of bamboo (3-4 inch) frame with dimensions of 12 feet × 12 feet for mainframe and 4 feet x 4 feet for diagonals. In each raft, around 20 polypropylene-twisted ropes (3 mm) are used for plantation. On this rope, around 150–200 grams of seaweed fragments are tied at a spacing of 15 cm along the length. A total of 20 seaweed fragments are tied in a single rope. The total seed requirement per raft is 60 – 80 kg. In order to avoid grazing by herbivorous fishes, fish net of 4m x 4m size is tied at the bottom of the raft. A 15 kg anchor is used to position a cluster of 10 rafts in the near shore area at a depth of 1.0 to 1.5 m during normal season and during rough season the depending upon the species. same cluster must be positioned using 2-3 anchors. Harvesting can be done after 45-60 days.



Longline or monoline method

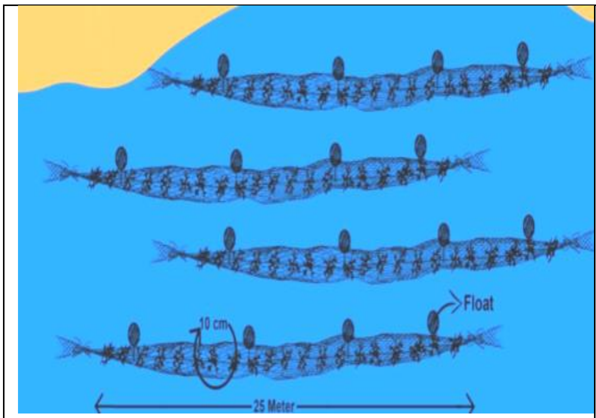
Longline method is ideal for areas with moderate wave action, shallow depth, and with less presence of herbivorous fishes. A rectangular seaweed farming area (120 feet length and 20 feet width) made up of 24 casuarina poles (10 feet length and 3- 4-inch dia each) form a unit. On one side, 12 casuarina poles are placed at 10 feet intervals and similar structure is erected parallelly 20 feet away. The poles are interconnected using a 6mm rope and the seaweed seedling rope is fastened to this. Around 150 grams of seaweed fragments are tied at a spacing of 15 cm along the length of a rope and a single rope contains around 40 fragments. The total seed requirement per rope is 6 kg and for entire segment is 60 kg. A total of 10 ropes (1 monoline unit) is equivalent to one bamboo raft in production. A fencing is made using HDPE fishing net to avoiding drifting and used PET bottles are tied on each rope for increasing the floatability. Harvesting can be done after 45-60 days depending upon the species.



(Photo credit: Dr Johnson B, Senior Scientist, Mandapam RC-CMFRI)

Tube net method

Tube net method can be adopted in locations with higher wave action. Tube nets having a length of 25 m and a diameter of 10 cm are made from HDPE nets having mesh size of 1.5 cm. These are kept floating in the water column below the surface with an appropriate number and size of floats at regular intervals. The seed material of 10-15 kg is loaded into the tubes with the aid of a 1-1.5 m long plastic pipe of lesser diameter than that of tube net. The plastic pipe is inserted into the tube net and the entire tube is pulled down, so that the mouth of 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. The entire tube net is seeded with seaweed fragments in this manner. Both the ends of tube nets are closed to avoid splitting. The tube-nets are positioned in the sea firmly with the help of anchors and floats. Anchor stones of about 30 kg are used at each end to hold the tube nets steady in the water column. Additional anchors of appropriate size and weight can be fixed intermediately if required. 4 tube-net units are equivalent to one bamboo raft in terms of production. In addition, tube nets can also be attached to rafts.



(Photo credit: Dr Johnson B, Senior Scientist, Mandapam RS-CMFRI)

The optimum water quality parameters for seaweed farming are temperature of 27-30^{0}C, salinity of 25 to 35 ppt, pH of 6.5-8.5, transparency of 2-6 m, light intensity of 100-125 µmol photon/ m2/s.

Revenue from seaweed farming of *K. alvarezii* (Modified from Johnson *et al*., 2020)

Bamboo raft/monoline method One bamboo raft/ monoline unit; each cycle is 45 days; total 5 cycles in a year	
Annual seaweed production (260 kg/raft or monoline per cycle) (After retaining 60 kg for next crop, total fresh seaweed production from 5 cycles)	1000 kg
Total seaweed production on dry weight basis (10 %) (from 5 cycles)	100 kg
Price of dried seaweed (Rs. per kg)	70
Gross Revenue (Rs)	7000
Total cost of production (Rs)	2000
Net income (Rs.)	**5000**
Tube net method Four tube-net units equivalent to one bamboo raft; each cycle is 45 days; total 5 cycles in a year	
Annual seaweed production (260 kg/4 tube net) (Retaining 60 kg for next crop, total fresh seaweed production from 5 cycles)	1000 kg
Total seaweed production on dry weight basis (10 %) (from 5 cycles)	100 kg
Price of dried seaweed (Rs. per kg)	70
Gross Revenue (Rs)	7000
Total cost of production (Rs.)	2500
Net income (Rs.)	**4500**

Different strains of *Kappaphycus*

Fisherwomen making seaweed lines

Harvested *Kappaphycus*

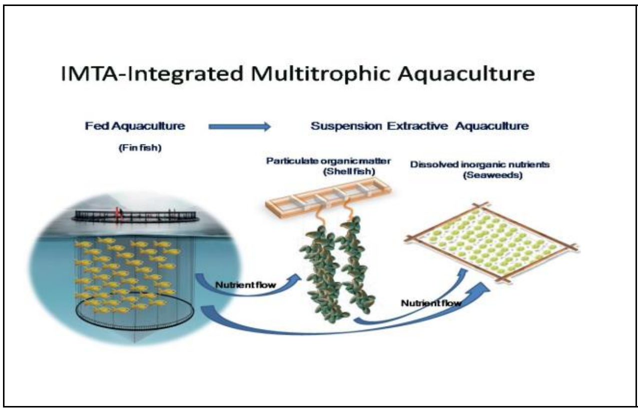
Apart from the culture of *K. alvarezii*¸ farming of native species of seaweeds for which technology has already been demonstrated can also be undertaken to meet the demand of seaweed industries.

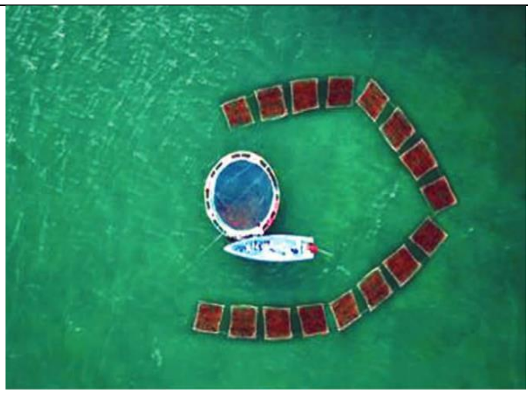
Species	Culture technology
Gelidiella acerosa	Bottom-culture method using coral stone as a substratum
Gracilaria edulis	Longline rope method using coir rope as substrate or Single Rope Floating Raft Technique (SRFT) method
Hypnea valentiae	Monoline or Longline method using vegetative fragments
G. dura	Monoline or Longline & Floating raft method using vegetative fragments
G. debilis	Floating raft method using vegetative fragments

Integrated multitrophic aquaculture (IMTA)

Seaweed farming also provides the coastal cage farmers to integrate seaweed in their cage farm, which not only reduces the adverse effects of aquaculture on the environment but also creates additional income. In this integrated multitrophic aquaculture (IMTA) systems, cage culture of fish can be integrated with bivalve and seaweed (extractive species) alone or together. The organic waste from cage culture is extracted by bivalves and inorganic nutrients are assimilated by seaweeds from the water. These extractive organisms can turn pollutant nutrients into commercial crops and loaded effluents into clean water. These systems thereby provide environment remediation (biomitigation), economic stability (improved output, lower cost, product diversification and risk reduction) and social acceptability (better management practices).

Mandapam Regional Station of ICAR-CMFRI has successfully demonstrated the integration of seaweed *K. alvarezii* farming in Cobia (*Rachycentron canadum*) farm. A total of 16 bamboo rafts (12 × 12 feet) with 60 kg of seaweed per raft were integrated for a span of 4 cycles along with one cobia stocked cage (6m diameter and 3.5 m depth with 1000 cobia fingerlings). Seaweed rafts integrated with cobia stocked cage had a better average yield of 320 kg per raft and was ready for harvest in 40 days. An additional 176 kg of seaweed per raft was achieved due to the integration with the cobia cage farming. In addition to increased production of seaweed, 357 kg of carbon was sequestered into the cultivated seaweed which was higher than in the non-integrated rafts (161 kg).





(Photo credit: Dr Johnson B, Senior Scientist, Mandapam RS-CMFRI)

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