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SEAWEED RESEARCH AND UTILIZATION IN INDIA

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SEAWEED CULTURE

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Seaweed culture has perforce to be adopted should the supply of raw material to Industries be uninterrupted ,like in the case of the Japanese and Korean *Porphyra* industries, the Chinese *Laminaria* industry and the Philippines *Eucheuma* Industry, which are now in the main based on cultured raw material. The culture is at present almost entirely confined to the Orient, reaching its peak of sophistication in Japan and China. The necessity of marine algal cultivation in India and the principles and problems involved therein are discussed by Thivy (1964), Krishnamurthy (1967) and Chennubhotla (1976).

There are several advantages in the cultivation of seaweeds. In addition to making possible a continuous supply of alga, crops of single species can be maintained continuosly; by taking proper care a harvest consisting of a desired seaweed unmixed with other algae can be obtained and this alga would be uniform in quality. By adopting scientific breeding and other modern techniques of crop improvement, the yield and quality of the seeweed could also be improved. Further, if seaweed cultivation is carried out on large scale, natural beds could be preserved purely for obtaining seed material.

Basically there are two methods for cultivation of seaweeds; one by means of vegetative propagation, using fragments, and the other by means of spores such as swarmers (gametes), oospores, tetraspores and carpospores. The vegetative propagation method, using fragments from mother plants, is a simple method and gives quick results, though a large number of mother plants have to be sacrificed for seed material. In the culture of seaweed from spores, the latter are first collected on suitable substrat such as bamboo splints and nets and these substrata are transplanted to the desired sites, where the seaweed can grow into harvestable size. The only disadvantage in this method is that it takes a long period for the development of spores to plants of harvestable size.

For cultivation of seaweed, suitable sites have to be selected and prepared for long-term usage. When seaweeds are brought under intensive cultivation, predators and diseases naturally increase and damage the crop. The culture sites can be protected from these with latticed fence, which would reduce surf action and at the same time allow free flow of water in and out of the enclosures. It also would prevent the entry of fish which may feed on the crop. Harvesting of the algae has to be done at the proper developmental stage, depending on the utility of the alga.

SEAWEED CULTURE IN INDIA

In India, seaweeds which are used as raw material in the seaweed industry are harvested from natural beds along Tamil Nadu and Gujarat coasts since 1966. There are about 21 agar industries and more than 25 algin factories in India (Silas and Kalimuthu, 1986). As many seaweed Industries are still coming up, there is an increasing demand for this raw material, particularly agarophytes, which the existing resources cannot meet.

Hence, the culture of seaweed is attempted at by Central Marine Fisheries Research Institute, Central Salt and Marine Chemical

Research Institute and National Institute of Oceanography.

CULTURE EXPERIMENTS IN CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

Since 1972, Central Marine Fisheries Research Institute is involved in the experimental culture of agarophytes *Gracilaria edulis* and *Gelidiella acerosa*; alginophytes *Sargassum wightii* and edible seaweeds *Acanthophora spicifera* and *Ulva lactuca* (Plates 3 & 4). It has developed a suitable technique for the large-scale culture of *G. edulis*. The rate of production of these seaweeds and also the economics of farming *G. edulis* are as follows.

Culture of Agar Yielding Seaweeds

Gracilaria: Culture experiments were conducted on *Gracilaria edulis* and *G. corticata* (Umamaheswara Rao, 1973). Fragments of *G. corticata* were kept in the twists of a small coir rope at regular intervals and the rope was suspended in seawater aquarium. Slow growth was observed for a period of 45 days and, thereafter, rapid increase in length from 1.8 cm to 5.5 cm was recorded during the next 45 days. Experiments on *G. edulis* were conducted in the sea near Mandapam, using coir-net frames of about 0.5 cm^2. Small fragments of *G. edulis* were introduced on each frame and were suspended horizontally in the sea. Many new shoots developed from the cut ends of the plant bits and, after 2 months, the entire frames were covered with plants of profuse branches. The average height of the plants varied from 14 cm to 16 cm and, at the end of 2 months, the plant bits that had been kept in the two frames gained weights, respestively, of 213 g and 257 g. From these experiments, the regeneration in *G. corticata* and *G. edulis* was found to be high, the plants growing to harvestable size with in 3 to 4 months.

To know if *Gracilaria edulis* can be cultivated in open-shore enviroment, field experiments were conducted in the Gulf of Mannar (Umamaheswara Rao, 1974 a). Two coir nets of 4 x 2 m size were used for seeding. Fragments of *G. edulis* of about 4.0 cm length taken from the apical parts of plants were inserted in the twists of the coir rope. Nearly 2.5 kg. of seed material was introduced for each frame and the frames, tied honizontally to poles with coir ropes, were kept at subtidal level so as to keep them permanently submerged. Harvesting was done after 80 days, leaving the basal parts of plants for further growth. The density of the crop varied on the two frames, and an average yield of 4.4 kg fresh seaweed was obtained from the seed material of 313 g per square metre area of the coir net.

Experiments were also carried out for cultivating *G. edulis* in the inshore waters of Gulf of Mannar, in submerged free-floating condition (Chennubhotla *et. al.*, 1978 a). Culture frame of 2 x 2 m size fabricated with teak wood and coir nettings of 7 cm mesh size made out of ropes of 2.5 cm and 1.3 cm thick were used. A total weight of 1.42 kg *G. edulis* fragments of 4.5 cm length were used for seeding, inserting them in the twists of the coir ropes. The frame was tied loosely to the poles fixed in the nearshore waters at 1 m depth in a submerged floating condition so as to facilitate its going up and down vertically according to the tide. Harvesting was made after 45 days. The fresh weight of the harvested meterial was 1.985 kg per square metre against the seed meterial of 355 g. The harvested meterial was pure, without contamination of other seaweeds and sediments. Thus, the submerged free-floating condition at 1 m depth is suitable not only for culturing the alga but also for obtaining pure cultures, without any contamination. The experiments conducted simultaneously at sub-tidal level were, however, hampered by much sedimentation, which adversely affected the growth of seaweeds.

Thus, the seaweed cultivation in the inshore waters is shown to be beset with problems such as sedimentation, as well as grazing of seed meterial and grown up plants by fishes. To overcome these constraints, cultivation of *G. edulis* was attempted at slightly deeper water, of 3-4 m depth, where sedimentation is less. The coir nets were replaced by nets made of hardened plastic (HDP) rope. The nets were of 5 x 2 m size, and were fabricated with ropes of 3 mm thickness, using 4 mm thick rope for their margins. The mesh size of the nets was 10 cm, and each net had altogether 1000 mesh intersections. The seed materials were tied at the mesh intersections with the help of nylon twine, and the nets were suspended at different levels with the help of plastic buoys and granite stone sinkers. Three such nets were introduced, with seed material of 665g m^2, at midwater level in a 4-m depth zone, and the yield after 90 days was 1617 g/m^2. Another net, containing 700 g seed material, was introduced just below the surface, and this yielded 2570 g/m^2 after 70 days.

Economics of Gracilaria edulis *Farming*

Based on the results obtained on the field culture of *G edulis* in the Gulf of Mannar and Palk Bay near Mandapam, Central Marine Fisheries Research Institute has evolved a technique for culturing *G. edulis* using coir rope nets (Anon, 1983). According to this method, one kg of seed material of *G. edulis* would yield on an average 3 kg per sq. m of net after 60 days. In one ha area of nets (i. e. 1000 nets) 30 tonnes fresh *G. edulis* could be obtained in one harvest. Six harvests could be made in a year if the condition of the sea was favourable. The nets could be used for several crops.

For the cultivation of *G. edulis* in one ha 1000 coir nets of 5 x 2 m size, 2000 casuarina poles of 1.5 m height and 10.000 kg of fresh seed material (for initial introduction) are required. The cost of 2000 casuarina poles is Rs. 6,000 and cost of 1000 coir rope net is Rs. 33,000, including charges for fabrication. The seed material can be collected for the initial introduction from the natural beds, and from the cultured crop for subsequent seeding. Wages for seeding, harvesting and maintenance of the seaweed farm for 4 persons at the rate of Rs. 10 per day for 360 days work out to Rs. 14,400. The total expenditure for one year would be Rs. 54,000, including miscellaneous expenditure of Rs. 600.

The estimated cost is arrived at on the assumption that a minimum of four harvests could be made in a year. A total of 120 tonnes (fresh weight) of crop could be obtained from the four harvests in a year when the yield is 3 kg/m^2. If the seaweed is dried (75% moisture) and marketed at a rate of Rs. 2000 per tonne, the net profit would be Rs. 6,000 for one year.

Gelidiella acerosa : Chennubhotla *et. al.* (1977 c) cultured *G. acerosa* by tying small fragments along with the substratum (coral piece) to the coir ropes interwoven in 4 sq m size G. I. pipe frames. The frames were tied in submerged condition to poles fixed in the inshore waters. One frame was introduced with 0.9 kg and the other with 1 kg seed material. The crop was harvested after 76 days and an increase of 1.6 kg and 2.0 kg was obtained, respectively. Recently field cultivation of *G. acerosa* was attempted in two methods. In one method, the fragments of the seaweed were tied to nylon twines at regular intervals and the seeded twines were then wound round the nails hammered into coral stones. The coral stones were kept in cages which were suspended at 2 m depth. In the other method the fragments of the seaweed were tied in the mesh intersections of the HDP rope nets and introduced at a 4 m deep station in floating condition with the help of plastic buoys and anchors. In one net of 5x2 m size introduced at mid water level with *G. acerosa* seed material of 650 g/m^2, the yield was 1300 g/m^2 after 55 days growth. Another net of 5x2 m size introduced just below the surface level yielded 1060 g/m^2 for the seed material of 650 g/m^2 after 60 days growth. The fragments of *G. acerosa* fastened to coral stones with the help of iron nails reached harvestable size after 5 months and 1.0 kg of seed material yielded 3.1 kg.

Culture of Edible Seaweeds

Acanthophora spicifera : Cultivation of *Acanthophora spicifera* was carried out in a pond (60 m X 30 m size) at the fish farm of Regional Centre of Central Marine Fisheries Research Institute, Mandapam Camp, which is situated on the Palk Bay side. The pond was connected to the sea through a feeder canal and so there was regular inflow and out-flow of seawater, depending upon the high and low tide, respectively. The depth of water ranged from 40 to 60 cm and the bottom was muddy with loose sand. The seeding on the nets was done in 2 HDP rope nets of 5X2 m size in the pond itself by keeping the nets in the water in order to avoid drying of seed material in the open air. The seaweed was cut into small fragments of 6 to 8 cm length and tied at the mesh intersections of the nets with the help of nylon threads. The culture nets thus seeded were tied in the centre of the pond to the palmyra poles already erected, at a level of 24 cm from the bottom of the pond so that they were always submerged even during the low tide conditions of the sea. The plastic floats were tied to the nets so that the nets may not sink to the bottom due to the weight of the plants when they grew. Seed material introduced was 620 g m^2 in both nets. Two harvests were made from the nets. The first harvest was made after 45 days growth. A yield of 2262 g/m^2 was obtained from the two nets and it was 3.6 fold increase over the initial seed material. The remnants were allowed to grow for the second harvest which was made after another 35 days. An yield of 1440 g/m^2 was obtained in the second harvest. There was no epiphytic growth of other algae on the nets Silt deposition was found on the plants but it had not hampered the growth of the seaweeds. These observations revealed that pond system is suitable for the cultivation of *A. spicifera* as similar culture experiments conducted simultaneously with *Gracilaria edulis Gelidiella acerosa, Hypnea valentiae, Sargassum wightii, Turbinaria conoides* and *Ulva lactuca* in the same pond did not give encouraging results due to too much sedimentation on the plants and also other factors like high salinity.

Ulva lactuca : Culture of *Ulva lactuca* was attempted in the laboratory in two plastic troughs (58 cm dia X 23 cm ht) with 20 cm water level. 50 g of excised pieces of *U. lactuca* were uniformly broadcasted in each trough. Aeration was provided for both troughs and the water was changed once in a week. The experiment was conducted in the varandah of the laboratory where the plants received direct sunlight for 4 hours during the after-noon hours and diffused sunlight during the rest of the day. Growth rate was determined by weighing the seaweed in each trough at every fortnight. The data were collected for a period of 75 days. The weight of the plants increased two fold after 15 days growth. Maximum weight of 120 g was obtained in each trough after 30 days and thereafter gradual decrease was observed. The weight of plant was 106 g, 85 g and 67 g after 45, 60 and 75 days growth respectively. Experiments on *Ulva lactuca* pretreated with Ascorbic acid and in different salinities have indicated that 18‰ boosts up the production to 8 times in 92 days.

SEAWEED CULTURE BY OTHER RESEARCH ORGANISATIONS IN INDIA

Some preliminary field and laboratory culture experiments were also conducted by other research organisations on the economically important seaweeds namely *Gelidiella acerosa, Gracilaria edulis, G corticata, Gelidiopsis variabilis, Gelidium pusillum, Hypnea musciformis, Hormophysa triquetra* and *sargassum* spp and the results obtained are given below.

Gelidiella acerosa: Bhanderi (1974 b) cultured *Gelidiella acerosa* for 105 days by vegetative propagation in aquarium. Vegetative fragments of 2.5 cm were obtained from the apical region of the plant, weighed and inserted in the twists of string of known weight and then suspended in an aquarium full of seawater. He observed a linear growth of 0.01 cm/day and an increase of 0.01 g/day in weight. Krishnamurthy *et. al.* (1975) conducted some experiments on *G. acerosa* in a lagoon on the southern side of Krusadai Island in November-December, ,1969 by inserting 2 cm fragments in the twists of ropes. In April, 1970, the fragments were grown into full sized plants, about 10 cm in length with 7 to 8 main branches.

Subbaramaiah *et. al.* (1975) conducted cultivation of *G. acerosa* in a shallow lagoon at Krusadai island. Planting was done using 2 cm apical fragments which were fastened to a nylon string at fixed intervals and the seeded string was wound round the rope. The rope was tied in the cultivation ground between poles and it was always submerged under seawater at a depth of 0.5 to 1.0 m. Three harvests were made during one year and the growth and harvest values were maximum in the third harvest during February and July. The maximum growth attained was 6.6 cm and the rate of production was 3.13 g/m/month(wet). The total production of seaweed was 421 g/m (wet.)

Experimental field cultivation of *G. acerosa* using coral stones as the substratum was done at Ervadi (Patel *et. al.*, 1979). An annual yield of 115.83 g/m² (dry) on overall basis was obtained which was 33 fold increase over the seed material. Patel *et al.* (1980) reported a maximum yield of 122 g/m² (dry) in one of their six monthly harvests made in January 1979 from the field cultivation of *G acerosa* at Ervadi.

Gracilaria edulis: Raju and Thomas (1971) cultured *G. edulis* by long line rope method in a sandy lagoon on the estern side of the Krusadi Island where the water is calm for most part of the year. Fragments of 1 cm and 2.5-3.0 cm length were used for planting and they grew to a length of 35-40 cm in about 5 months period. Three harvests were made at the end of 5, 8 and 10½ months after planting and the total harvest during the year was about 3.5 kg from 1 m length of rope.

Krishnamurthy *et. al.* (1975) carried out cultivation of *G edulis* in a lagoon on the southern side of Krusadai Island in June and July, 1967. Fragments of 2.5 cm length removed from the apices of the healthy plants were inserted between the twists of ropes, one each at intervals of four inches along the length of the ropes. These ropes were tied to bamboo poles planted to the sea bottom and adjusted at a level of roughly one foot above the bottom. In about 5 months, the plants attained a length of about 30 cm and the average weight of plant was about 300 g. In the fifth month, a harvest was made by clipping the plants close to the rope and the remnants were left on the rope for further growth Two more harvests were made at intervals of 10 weeks, thus giving 3 h.rvests in a period of 10 months.

Other red algae: Bhanderi (1974 b) recorded a linear increase of 0.02 cm/day and an increase of 0.07 g/day in the weight in his culture experiment on *G. corticata* in seawater aquarium. Bhanderi (1974 b) cultured *Gelidiopsis variabilis* for 105 days by vegetative propagation in an aquarium. The linear increase obtained was 0.12 cm/day and the increase in weight was 0.04 g/day.

Mairh and Sreenivasa Rao (1978) cultured *Gelidium pusillum* in the laboratory under free floating conditions using different enrichments and under controlled conditions of light and temperature. The plants grown under different photoperiods as well as under continuous illumination reached maximum fresh weight and full size within 3 to 4 months This experiment showed that fragments of *G. pusillum* as small as 2 mm in length can regenerate without any loss in their capacity to produce proliferations.

Rama Rao and Subbaramaiah (1980) culture *Hypnea musciformis* in the lagoon of Krusadai Island. Vegetative fragments of *H. musciformis* were used as seed material and cultured in long line rope. Fourfold increase in biomass in 25 days growth was achieved.

Sargassum *spp:* Thivy (1964) conducted culture experiments in ponds at Porbander by attaching small plants of *S. cinctum, S. vulgare* and *S. wightii* to coir nets with the help of tape. The seed materials were collected from their natural beds of reef at Porbandar and their size ranged from 5-10 cm length. The plants of *Sargassum* grew to a height of 15 to 52 cm within forty days and most of them were in fruiting condition. The experiment revealed that there are good possibilities for cultivation of *Sargassum* and other seaweeds in India.

Hormophysa triquetra: Bhanderi and Trivedi (1977) made an attempt to study the possibility of culturing *Hormophysa triquetra* by vegetative propagation in an aquarium. Stipes of about 3 cm size without fronds and fragments of 3 cm size distal end of fronds were obtained, weighed and then inserted at the intervals into the separate nylon strings. The rate of linear growth of stipes was found to be 0.083 cm/day while that of the fronds was slightly more i. e. 0.085 cm/day. At the end of the cultivation period the stipes had increased the fresh weight equal to that of its inserted weight at a rate of 0.089 g/day. The fragments gained 7 times fresh weight than that of their initial weight at a rate of 0.333 g/day.

SEAWEED CULTIVATION IN FOREIGN COUNTRIES

The important seaweeds for which commercial cultivation is practised or is being developed are *Enteromorpha, Monostroma* and *Ulva* (green algae); *Alaria, Ascophyllum, Ecklonia Hijikia, Sargassum* and *Undaria* (brown algae) and the red algae *Agardhiella, Chondrus, Eucheuma, Furcellaria, Gelidium, Gigartina, Gloiopeltis, Gracilaria, Hypnea, Porphyra* and *Rhodymenia* (Neish, 1979 and Saito, 1979). The seaweeds cultivated in different countries in the Indo-Pacific region and the extent of development are given by Ling (1973). At present edible seaweeds are intensively cultivated in Japan, Korea and China. The genera cultivated in North-West Pacific are *Porphyra. Monostroma, Enteromorpha, Undaria, Laminaria* and *Nemacystus.* The red alga *Eucheuma* is cultivated in the Philippines (Satio, 1979).

Culture of Red Algae

Porphyra: The genus *Porphyra* is known as 'Laver' in European and American countries and as 'Nori' in Japan. The methods of its cultivation are reviewed by various authors (Tamiya, 1960; Kurogi, 1963; Thivy, 1964; Krishnamurthy, 1967; Sreenivasa Rao, 1967; Ryther 1968 a; Bardach *et. al.* 1972; Furukawa, 1973; Ling 1973; Miura' 1975; Background, 1976 and Saito, 1979). *Porphyra* culture has a history of over 200 years in Japan. It began in Tokyo Bay in the 17 th century. The original culture method involves placing bundles of leafless branches of bamboo, oak or other trees at or just above the mean water level in areas located well away from brackish water during winter (September to October). Within 2 to 4 weeks the non-motile monospores settle on the branches and develop into leafy thalli. The branches along with the leafy thalli are moved inshore preferably to an area such as around a river mouth where high concentrations of dissolved nutrients occur. The thalli grow there and are harvested periodically. Though the method has now become obsolete in Japan, it is still practised in Korea.

Efficient culture methods were developed only after the second world war and the industry expanded rapidly and extensively in Japan and Korea after the discovery that the Conchocelis stage of the alga is passed in a shell during summer and produces monospores, which grow in to the leafy thallus. This discovery provided the basic knowledge for the development of technique for mass production of seedlings under controlled conditions.

The most successful and common practice of *Porphyra* culture is known as 'floating rack method'. The racks are made of bamboo and are set in shallow coastal areas where the water is clean and comparatively well protected from storms and heavy wave action. A net with seedlings attached is hung horizontally on each rack. The net is made of plant or synthetic fibre about 18 to 45 m long and 1.3 to 1.5 m wide with a mesh size of about 33cm.

The preparation of seedlings (production of monospores from Conchocelis) under controlled conditions is done during winter (December to March). Conchocelis are induced to produce monospores by various temperature and chemical treatments. The monospores attach readily to the net when it is passed through the tank which contains the spores. The nets with monospres attached may be made into single unit sheet or into a roll that can be cut into 10 to 25 sheets and stored under a temperature of 20°C to 24°C for several months with the spores remaining viable. Within 15 to 20 days after the setting of nets the alga grow to 10 to 15 cm length, when the first harvest is done. The remaining plants continue to grow and harvest is repeated 3 to 4 times before the net is replaced.

Gracilaria : Culture of *Gracilaria* is being practised fairly successfully since 15 years in Taiwan in shallow coastal flats and ponds and is expanding steadily. The method of *Gracilaria* culture at Taiwan is described by Chen (1976). Of the 4 species of *Gracilaria* of economic importance viz. *G. gigas* (= *G. chorda*), *G. confervoides*, *G. lichenoides* and *G. compressa*, *G. confervoides* is the species most commonly cultured in ponds. *G. gigas* is also cultured in some areas. Culture of *Gracilaria* started in 1962 and the cuttings of *Gracilaria* are used as planting stock. Each plant is cut into pieces, which are planted uniformly usually in April on the bottom of the pond. 3000 to 5000 kg of the fragmented plants are planted in a pond of one hectare size. The planting stocks are placed uniformly on the bottom. They are usually fixed on bamboo sticks planted on the bottom or covered with old fish nets to prevent them from drifting to one side or one corner of the pond. Either organic or inorganic fertilizer is used to accelerate the growth of *Gracilaria*. Harvest by hand or by use of scoop nets is done once in 10 days from June to December. *Gracilaria* is cultivated as side crop in some places in Philippines (Blanco, 1973). Substrate additions to increase stocks of *Gracilaria* has also been practised in tropical areas by spreading dead coral over predominantly sandy areas where these seaweeds can not attach (Neish, 1979). Culture experiments in the laboratory with plant segments of *Gracilaria debilis* were conducted by Goldstein (1973). The segments regenerated branches from the cut surfaces and they showed rapid vegetative propagation when coral stones and lime stone blocks were used as substrate.

Eucheuma : The culture of the red algal genus *Eucheuma* is described by Blanco (1973), Kow *et. al.* (1973), Parkar (1974) and Deveau and Castle (1979). Two methods of culture have been developed for *E. cottonii* namely the net method and line method. The method using net consists of fabricating 2.5X5 m size nets with monofilament nylon and with a mesh size of approximately 0.3 m (1 foot). Each net has 127 mesh intersections where vegetative fragments are tied. The nets are installed horizontally 0.6-1.5 m above the bottom and below lowest tide depth by attaching net corners to mangrove wood poles, driven in the reef bottom, an area previously tested for growing ability. The nets are seeded with 100 g pieces of seaweed by tying them to the net with a thin plastic strip which does not cut the fronds and allows them to move in the current. Once the plants have reached a weight of 1200-1500 g they are pruned to 500 g and the process continues. Attempts are being made to grow *E. spinosum* commercially. A brief account of the experimental cultivation of *E. spinosum* in Singapore water and culture conditions are given by Kow *et. al.* (1973).

Tank culture method of *Eucheuma* was given by Deveau and Castle (1979). *E. isoforme* was cultured in tank and the basic cultivation system used was a square tank with a slanted bottom and its water was agitated by bubbling air into the deepest part of the tank. This established a circulation pattern strong enough to keep the dense *E. isoforme* in constant suspension and this assured that all plants would receive their share of sunlight and be uniformly exposed to the dissolved nutrients in the seawater. The tank culture method was sought for developing a controlled combined supply of the raw material of *Eucheuma* to that cultured in the sea.

Culture of other red algae: A number of other algae are cultured in Japan. The most important edible alga cultured is *Gloiopeltis* (Funori) which is used in the manufacture of glue. Production of *Gloiopeltis* has been increased by simply placing boulders or chunks of concrete at suitable locations in the sea to provide substrate for settlement. Advanced experimental culture of *Hypnea* sp. in the Philippines are based on suspending thalli, under protected and other optimal growing conditions (Bardach *et. al.*, 1972). Some measures of success had been achieved in the culture of *Chondrus crispus* (Saito, 1979). The method consists of propagating *Chondrus* in detached from in agitated ponds or tanks. Although this technique is still in the initial stage, it is under active commercial development and is expected to produce significant quantities of Chondrus within the next 5 years. This system is also being considered for culture of *Gigartina* and *Hypnea* (Neish, 1979). *Hypnea musciformis* was cultured (Guist *et. al.*, (1982) in outdoor plywood tanks (2.4 m x 1.2 m; maximum depth 1.1 m; minimum dapth 0:5 m; 2.9 m^2 surface area and 2400 1 capacity) at Summerland Key, Florida for 15 months. A continuous flow of untreated seawater (790 1/h) was supplied to each tank, Each culture tank was agitated with a continuous flow of compressed air pumped through a sparger located along the deep end of the culture tanks. Sodium nitrate, ammonium nitrate or ammonium sulphate was used as the source of nitrogen, while trisodium phosphate served as phosphate source. Enriched tanks received 208-400 µM of nitrogen and 1.6 - 3.2 µM. of phosphate each day. The highest growth rates were observed when the water temperature was between 18° and 24°C and with continuous water flow, supplemental nitrogen and phosphate and an initial biomass of 1.86 kg weed per square metre of surface area in the culture. tanks.

Culture of Brown Algae

A few brown algae, mostly the large species known as kelp are cultured. In Japan the most important brown algae cultured are *Undaria pinnatifida* (Wakame) and *Laminaria* spp (Konbu). Among these two, *Undaria pinnatifida* is more intensively cultivated.

Undaria: The culture method of *Undaria is* given in detail by Ryther (1968 b), Bardach *et. al.* (1972) and Saito (1975). Until the late fifties. methods of culture of *Undaria* were extremely primitive and consisted of only anchoring plastic floats at suitable depths for attachment of young plants. By about 1956, a technique of artificial spore production was worked out at Onagawa, in the Sendai region of northern Honshu. Most of the increase in the production of *Undaria* can be attributed to the introduction of artificial spore collection technique developed in 1960. The preparation of seedling culture begins at the end of the season when *Undaria* plants mature and develop zoospores. Seedling twines are used for spore collection and the culture of germlings, The meterial used for seedling twine is mostly synthetic fibre yarn of 2 3 mm diameter. The 100 m long twine is wound around at intervals of about 1 cm in a square plastic frame of 50 x 50 cm size.

Mature sporophytes of *Undaria* which have been partially dried are placed in concrete or plastic tanks filled with fresh seawater. The sporophylls are removed after a large number of spores have been released in the seawater. The string or twine frames are arranged in layers inside the tank to collect the zoospores. The frames are removed after 1 or 2 hours and hung vertically in culture tanks of about 1 m depth. The seedlings which develop are cultured throughout the summer. Within the tanks, according to changes of water temperature, light intensity is regulated so as to keep the growth of the gametophytes in good condition and their survival rate at high level. If necessary the tank water is changed, circulated or supplied with nutrients. The frames with their seedling twines are later taken from the tanks and suspended in the sea from a raft in order to raise the germlings into healthy young thalli until they grow to 2.3 cm in length. Operations for growing *Undaria* thalli start in autumn (September - November) when the water temperature falls below 20°C and danger of attachment of epiphytic organisms diminishes. Seedling twines are attached to a 10-20 mm diameter synthetic fibre rope at suitable intervals. Sometimes the twine is cut into short pieces of 5-6 cm length and inserted in twists of the rope. The cultivation ropes are set in the sea by hanging from bamboo rafts or buoyed long lines. In rough waters, 100 m long cultivation rope is held in the sea with buoys and anchors and many ropes are aften hung from the main rope. In calm waters like bay, the ropes are stretched out horizontally in the sea by rafts. When the thalli have grown to more than 50-60 cm in length, harvest is made by hauling the rope to a boat and cutting the thalli with the sickle. The use of seedling twines for the cultivation of *Undaria* was started in Korea in about 1960. In China after the second world war both *Undaria* and *Laminaria* cultivations were industrialised.

Laminaria : Methods of *Laminaria* cultivation are elaborately given by Bardach *et. al.* In Japan until 1943 cultivation of *L. Japonica* was confined to the practice of throwing stones bearing spores or young sporophytes into the sea. Attempts at more intensive culture both on rafts and on bottom were made by the Japanese. The basic technique involved in artificial propagation of *L. japonica* consists of collecting zoospores from sporophytes in late autumn and lodging them on short ladders made of bamboo splint and hung from floating rafts. Young sporophytes appear on the ladders by January and are removed for use in one of the methods of *Laminaria* cultivation.

The earliest attempts at culture of *Laminaria* sporophytes involved growing the plants on the sea floor. Bottom culture is still employed in China as well as in Japan and Korea, but most of the tremendous increase in the Chinese production of *L. japonica* has come as the result of various forms of raft culture. Rafts which are generally anchored to stakes driven into the bottom in water at about 10m depth are of 3 types namely basket raft, single line tube raft and double line tube raft. The details of these 3 types of rafts are given by Bardach *et. al.* (1972).

Productivity is generally calculated in terms of amount of algae produced per kg of fertilizer. Though the basket raft required somewhat less labour to operate and produce higher quality of Laminaria, it yields about 1 kg of algae per kg of fertilizer, while the single line and double line tube rafts are capable of producing 3.75 kg and 3.0 kg of algae respecti vely per kg of fertilizer. So the single line tube raft is most popular.

Bottom culture of *L. japonica* persists in China largely because of the low cost in terms of labour, material and capital investment. Bottom culture is also carried out along with raft culture to take advantage of excess fertilizer. In addition, growth of *Laminaria* on the sea floor is encouraged because the plants provide shelter for various edible fishes and invertebrates which in turn help to fertilize the algae.

The classical method of bottom culture is called 'stone casting'. Originally stone casting consisted of not more than placing large stones, averaging 16 kg in weight in the shallow water to provide an attachment surface for naturally produced zoospores Now zoospores are collected and allowed to attach to the stones before deposition. The Chinese have brought exposed rocky areas into production by construction of 'tiered farms'. These culture areas consist of pools of varying depth from 40 to 150 cm bounded by rock and cement dams of graduated height. Stones are placed in the pools for attachment of zoospores. A cheap and simple method of culturing *L. japonica* is to attach young sporophytes directly to ropes anchored on the sea floor. This technique is being tested in China but is still in the experimental stages.

Cultured *L. japonica* sporophytes reach a length of more than 3 m in 4 to 5 months and they are large enough for harvest. The maximum length attained in raft culture is above 6 m. Raft cultured *Laminaria* is harvested from boats, but harvest of bottom grown plants is made with the help of trained divers.

Macrocystis : The culture of the giant kelp *Macrocystis* is described by Saito (1979). In the United States, seedlings of *Macrocystis* have been cultured on plastic rings and the rings set on rocky substrates using an under-water epoxy cement. Recently in the U. S. methods for mass culture of *Macrocystics* embryos and their dispersal into the sea have been developed. Seedlings attached to polye-thylene film substrates or glass fibre cloth substrates are cultured in a refrigerated room in a long tray through which chilled filtered and sterilized seawater flows. The embryos growing on the substrates are scraped out, suspended in seawater and dispersed on a rocky bottom by pouring them down through a hose. Sometimes dispersal is done by a diver. These methods seem to be effective in the restoration of kelps resources. In North America preliminary investigations are underway by carrageenan producing companies to determine whether the hatchery produced macrophytes can be grown economically in a detached form in agitated culture tanks (Neish, 1979).

Culture of Green Algae

The green algae commonly used as food by man are *Enteromorpha* and *Monostroma*. Bardach *et. al.* (1972) have given an account of the culture of green algae in Japan and Taiwan. In Japan these algae are cultured along with *Porphyra*. *Monostroma* is cultured separately. Similar to *Porphyra* culture, the crop of *Monostroma* is grown on nets suspended horizontally at intertidal levels near river mouths. From a net of 36 x 1.5 m size usually 3 crops of 10 kg. 10 kg. and 6 kg (wet weight) are harvested after 100, 45 and 30 days respectively. The methods used in the highly successful culture of *Gracilaria coronopifolia* in Taiwan have been adapted to farming of *Caulerpa* sp for the fresh vegetable market in the Philippines. *Caulerpa* is grown in brackish water ponds seeded with chopped fresh pieces of the mature plant.

Selection of Strains of Seed Stock

Vegetative propagation of selected clones is a commercial reality in the Philippines, where various strains of *Eucheuma* are cultured. Selection of fast growing clones with desirable characteristics contributed to the high productivity of *Eucheuma* in Philippines. Selected strains of seed stock of *Chondrus* grow 2 to 3 times as fast as mixtures of wild stock (Neish, 1979). In China fast growing *Laminaria* strain such as Hai-Ching No. 1 have increased yields.

Use of Fertilizer in the Culture of Seaweeds

For intensive cultivation natural nitrogen levels are inadequate in most of the areas. Hence nitrogen fertlizers are used in *Porphyra* and *Laminaria* cultivation. In *Porphyra* culture, whenever the nutrients are poor culture sites are fertilized to get a better quality of harvest. In Japan the aim of fertilization is to obtain a high survival rate of young nori and to prevent the discolouration of older plants. The fertilizer is used at the rate of 600 mg/m^2 of water area and continuously for 2 to 3 days. The composition applied at the rate of 150 mg/m^2 of water area are given by Furukawa (1973). The fertilizing methods in the culture of *Laminaria* by basket raft and tube raft system are given in detail by Bardach *et. al.* (1972). Some culturists give a head start to young sporophytes of *Laminaria* by immersing them in a solution of fertilizer, usually ammonium nitrate. Absorption of nitrogen by plants so treated has been found to increase with concentrations up to 1 g/m^2 when the time of immersion does not exceed 6 hours. Stronger solutions may be used if the immersion time is reduced accordingly. 15 minutes is sufficient in a solution containing 400 g/m^3 of fertilizer. Immersion accompanied by aeration and constant stirring may be carried out weekly. The fertilizer solution may be reused several times. Culture of *Laminaria* in sterile waters such as the Yellow Sea greatly increased the demand for chemical fertilizer, which are already in high demand and low supply for the use on terrestrial crops. Chinese researchers are currently considering another substitute source of fertilizer for *Laminaria*, and it is the large scale introduction of nitrogen fixing algae and bacteria in the Yellow Sea.

Experiments conducted by Parkar in Zamboanga, Mindanao (Philippines) in 1972 revealed that in *Eucheuma spinosum* test plant growth rates increased by 40-50% when 4.8 kg ammonium sulphate (21% Nitrogen and 24% sulphur) was applied to the test area over a 10 day period. Control plants showed no increase in growth rates during the same period. In Taiwan the growth of *Gracilaria* is accelerated by using either organic or inorganic fertilizers. In some areas 3 kg of urea are supplied weekly to one hectare pond and in some other farms 120to 180 kg of fermented manure from pigsties are supplied to each hectare of the pond every 2 or 3 days at the time when water is being introduced (Chen, 1976).

Fertilizer pellets were applied in the field cultivation experiments of *Gelidiella acerosa* at Mandapam (Mairh *et. al.* 1979) with a view to get higher yield of the alga. These pellets were tried in the field rope cultivation of *Gelidiella acerosa* in a slotted polythene bag tied per metre rope. During nine months period, the pellets gave 20 to 30% increase in yield per metre rope over the control experiment,. There was no much change in the quantity and quality of agar obtained from the fertilizer supplied material and control.

Fertilizers are not used for culture of seaweeds in Korea. In general, fertilizing is not economical primarily because a system of slow and uniform release of fertilizer in sufficient quantities has yet to be perfected. One could consider fertilizing the culture area with inorganic fertilizer but tide would wash too much fertilizer away into non-exploited areas.

Use of Growth Promoting Substances or Hormones in the Culture

Studies on this aspect were carried out by Davidson (1950) on the growth of vegetative thalli of *Fucus evanescens* and *Ascophyllum nodosum* and by Oza (1971) on *Gracilaria corticata*. In all these cases low concentrations of IAA progressively stimulated the growth of the algae while higher concentrations were found to be lethal. Provasoli (1957) demonstrated the positive response to the exogenous application of gibberellins in *Ulva*. Raju (1971) conducted experiments on the effect of growth hormones and fertilizers on the phostosynthetic carbon assimilation in *Ulva fasciata*, *Sargassum* sp. and *Gracilaria corticata*. The photosynthetic uptake of C^{14} was maximum in *Gracilaria corticata* followed by *Ulva fasciata* treated with gibberellic acid. In *Sargassum* maximum effect on photosynthetic C^{14} assimilation was observed in plants supplied with ammonium sulphate. The effect of a morphaction on the vegetative growth of *Gelidiella acerosa* was studied by Tewari (1975). Chlorflurenol in hormonal range increased the fresh weight and the number of proliferations. But the elongation growth of the alga was inhibited. The possible applications of chlorflurenol for marine algae was also discussed (Tewari, 1975). Chauhan and Joshi (1979) reported that indole-3 acetic acid at the concentration of 10^{-6} M proved stimulant on the growth of *Sargassum swartzii* germlings than the other concentrations tried. The 10^{-3} to 10^{-6}M concentration of gibberellic acid helped in increasing the length of pseudophylls of the sporelings.

Diseases

Diseases are a matter of extreme concern in most intensive algal monoculture enterprises. Fungal, viral and external diseases have been described in *Laminaria* and *Porphyra* culture. At times diseases occur in *Porphyra* culture in association with unsuitable weather, environmental conditions in the sea and with overpopulation of the plants in the cultivating ground (Saito, 1979). The nori plants are susceptible to disease and most of the diseases are bacterial in nature. A fungus disease caused particularly by *Pythium* sp is lethal to *Porphyra* thalli, particularly at temperature above 10°C. When prevalent, this may wipe out 50% or more of the nori crop. Fungus may be at least partially prevented by exposing the seaweed to air during part of the tidal cycle. On the other hand, too much exposure may reduce growth and toughen the thallus, making it unsuitable for food. The most satisfactory compromise is to expose the algae for approximately 4 hrs/day (Bardach *et. al.*, 1972). The knowledge acquired on the disease resistance of various species of *Porphyra* is duly applied in selecting the variety to be grown. If disease has been observed in a crop, extra care has to be taken in washing and drying the nets before reusing them. Disinfectants have not been used so far (Background, 1976).

There is a disease problem also in the culture of *Undaria* and it causes detachment of young fronds and can result in a serious reduction of the crop. The origin and nature of the disease is not known. A number of diseases including various rot diseases are reported in *Laminaria japonica* but no effective means of control has been found (Bardach *et. al.*, 1972).

Predators, Fouling Organisms and Epiphytes

Predatory organisms attack the nori crop only when other seaweeds settle on the nets. These include green algae such as *Enteromorpha* and *Ulva* and also some diatoms. Careful manipulation of the level of the nets can overcome this problem. Most of the competing algae can not withstand exposure to air as much as the nori but one should be careful to avoid drying out of the nori plants as this is fatal to them (Background, 1976). Fouling organisms mainly barnacles settle on *Undaria* and cause some dificulties. But they do not result any heavy losses. Similarly predators and fouling organisms including bryozoans ascidians, amphipods and unwanted algae are found on *Laminaria japonica*. But no effective measures of control have been found for any of these constraints (Bardach *et. al.*, 1972)-

Transplanted buds of *Macrocystis* are often eaten by gastropods and other grazers, resulting in failure in their propagation. Two methods have been tried to prevent this damage to the buds. One method is to try to supply these grazers with additional food by cultivating a large amount of seaweeds at or near the surface of the sea as a substitute for the food otherwise provided by young plant buds. These trials have been carried out on a large scale in northern districts of the Pacific coast of Japan. In the other method, after the concrete blocks wound with seedling twines bearing young buds are set out, they are covered by cages of synthetic fibre twines and the harmful grazers in the cages are removed. The cage is in the shape of a box (1.5 X 3 X 3m) or a cylinder (3 to 10m in diameter and 3 m height). The cage remains as protection from grazers until the plants become adult. This method has been tried in the southern districts of Japan and similar trials have been made in California (Saito, 1979).

The major predators in the culture of *Eucheuma* at Philippines are sea urchins. However, as the plants are elevated and as long as eel grass is kept short, sea urchins are not a serious problem. The farmers secure and remove them with a sharp stick. The epiphytes if unchecked will cover nets and plants of *Eucheuma* and reduce the growth. To accomplish this, the farmers brush nets with a plastic scouring pad and clean the plants with their fingers (Parker, 1974).

In India, the fishes *Signaus javus* and *S. canaliculatus* were found to feed voraciously on the cultured seaweed *Gracilaria edulis*. The crabs *Thalamita crenata* and *T. integra* cause extensive damage to growing parts of the seaweed by merely clipping them with their chelipeds as they crawl about amongst the seaweed (James *et. al.*, 1980). The 'problem of predators can be solved to a great extent by enclosing the cultivation area with a latticed fence or a net of a suitable mesh size.

Culture of Spores

The number of spores produced by an alga is enormous. In nature only a small number of spores grow to mature plants since viability, settlement and development of these spores are controlled by many hydrobiological factors such as water movement, tidal exposure, water temperature, competition for space and predators or grazing organisms. But when these spores are raised into germlings on suitable substrata in the laboratory or nursery and then transplanted to the field, a high rate of germlings grow to harvestable size plants. Some work in the direction of culturing the spores of economically important seaweeds was carried out in recent years. The estimate of spore output was made in a number of algae by different workers and the data are presented in Table 13. Periodicity in the liberation of spores was observed in *Ulva fasciata*, *Cystoseira*, *Sargasaum swartzii* and *Gracilaria verrucosa*, but there is no such periodicity in *Sargassum wightii* and species of *Turbinaria*. Some information has been collected by Subbaramaiah *et. al*. (1967). Chauhan and Krishnamurthy (1967), Mairh and Krishnamurthy (1968), Krishnamurthy *et. al*. (1969), Subbaramaiah (1970), Raju and Venugopal (1971), Chauhan (1972) and Umamaheswara Rao and Kaliaperumal (1976) on settlement and development of germlings of different species of seaweeds in the laboratory and transplantation in the sea. Subbaramaiah and Krishnamurthy (1967) described the condition and media developed in recent years for the culture of seaweeds in the loboratory.

Subbaramaiah *et. al*. (1967) cultured germlings of *Ulva fasciata*. The germlings were kept growing in attached or in a free floating condition in petridishes containing sterile seawater which was changed once a week. In 2 months the germlings differentiated into cylindrical plants with 2-3 branches arising from the basal cells. The floating plants were longer (1.25-1.7 m) and produced branches while the attached ones were shorter (0.75-0.83mm) and unbranched. The growth of germlings did not advance beyond the cylindrical from during these 2 months. Subbaramaiah (1970) observed the settlement and growth of germlings of *Ulva fasciata* under laboratory conditions using a variety of artificial substrata like shells, stones, bamboo stems (entire and split), coir rope, nylon string and plain glass. The germlings attained a size of 5 mm in 100 days when they were raised on nylon string. The swarmer formation, liberation, settlement and growth of germlings on nets were also obtained in an experimental pond. The germlings attained on the average a length of 24.3 mm and breadth of 5.7 mm in 60 days. The effect of different culture media on growth and sporulation of laboratory raised germlings of *Ulva fasciata* has been given (Oza and Sreenivasa Rao, 1977). Kale and Krishnamurthy (1967) studied the effect of different media like plain seawater, Erdschreiber seawater and artificial seawater medium (modified ASP-6) on the growth of germlings of *Ulva lactuca* var. *rigida*.

Mairh and Krishnamurthy (1968) observed 100% germination of oospores of *Cystoseira* and subsequently 94% of their survival. The germlings survived and grew into young healthy plants under experimental conditions. Chauhan and Krishnamurthy (1967) cultured the oospores of *Sargassum swartzii* in petridishes lined with filter paper. They developed into germlings and some of them grew for a period of 5 weeks. Experiments were also conducted using different substrata such as coral pieces, shells, granite stones, nylon threads and rough stones. Some of the oospores attached to the substrata and developed into healthy germlings while a large number did not survive. Continuous illumination of the culture experiments with a light intensity of 600-800 lux, 23°-26°C temperature and circulation of a thin stream of filtered seawater were found favourable for healthy growth of germlings. Chauhan (1972) observed the survival of germlings in *Sargaasum swartzii* for about 6 months under the controlled laboratory conditions. Of the eight different substrata used, the cement concrete blocks, bricks and filter paper were found to be good substrata as they retained 84.55%, 78.42% and 62% of the germlings respectively. The filtered seawater and seawater with enrichment were found to be the most suitable culture media for the growth of germlings. The use of media like ASP-6 and ASP-12 did not give good growth of germlings. Continuous illumination was more beneficial than 18 hours photoperiod.

Raju and Venugopal (1971) made an attempt to allow the oospores of *Sargassum plagiophyllum* to settle on a concrete substratum with a view to finding out the time required for the appearance and growth. The

Table 13

Spore output in Indian marine algae

Algae (1)	Type of spore (2)	Number of spores liberated (Maximum spore output) (3)	Authors (4)
Ulva fasciata	Swarmers (Gametes)	1,15,34,400 spores/plant	Subbaramaiah *et. al.*, 1967
Cystoseira indica	oospores	5,11,251 ,,	Mairh and Krishnamurthy, 1968
Sargassum swartzii	,,	5,53,331 ,,	Chauhan and Krishnamurthy, 1967
S. wightii	,,	3,70,272 ,,	Umamaheswara Rao and Kaliaperumal, 1976
Turbinaria conoides	,,	11,312 ,,	Chennubhotla *et. al.*, 1978 b
T. decurrens	,,	28,196 ,,	Kaliaperumal and Umamaheswara Rao, 1975
T. ornata	,,	33,810 ,,	Kaliaperumal *et. al.*, 1977
Gelidiella acerosa	Tetraspores	20,000 ,,	Sreenivasa Rao, 1969
do	,,	10,000 Spores/g fr. wt./day	Umamaheswara Rao, 1974 b
Gelidiopsis variabilis	,,	2,60,940 ,,	Kaliaperumal and Umamaheswara Rao, 1982
Gracilaria corticata	,,	3,98,000 ,,	Umamaheswara Rao, 1976
do	Carpospores	2,374 Spores/Cystocarp/Day	,,
do	,,	8,66,700 Spores/plant	Mohan Joseph and Krishnamurthy, 1977
G. edulis	,,	6,49,873 ,,	Rama Rao and Thomas, 1974
G. millardettii	,,	42,782 ,,	Krishnamurthy, 1967
do	Tetraspores	68,520 ,,	,,
Gracilaria verrucosa	Carpospores	70,000 ,,	Oza and Krishnamurthy, 1968
Hypnea valentiae	,,	7,01,607 ,,	Rama Rao, 1979
do	Tetraspores	3,14,914 ,,	,,

concrete cylinders were lowered in *Sargassum* beds. Observation revealed that the appearance of *Sargassum* germlings on the cylinder took 10 months and it took another 8 months to grow to maturity. Observations after one more year revealed that there were a number of new plants which had germinated from the spores within the year and some had regenerated from persisting holdfasts. There appear to be a potentiality for regeneration for a third year in a few plants. Umamaheswara Rao and Kaliaperumal (1976) maintained the oospores of *Sargassum wightii* in a medium of seawater enriched with agar and found that 47.6% of germlings were in healthy condition at the end of 60 days.

Krishnamurthy *et. al.* (1969) raised the germlings of *Gracilaria edulis* and *G. corticata* on a nylon fabric from carpospores under laboratory conditions. Then they were transferred to the sea. After four months young plants appeared and they took another four months to attain maturity and develop reproductive structures.

From all these studies it is clear that with proper care and under controlled conditions of the laboratory a high rate of survival of germlings can be achieved and transplantation of germlings to the sea could be done successfully if any large scale culture of seaweed has to be undertaken. The rhythmic liberation of spores also indicates the possibility of successfully raising the germlings in a nursery and further culture.

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