TECHNICAL RESOURCE PAPERS REGIONAL WORKSHOP ON THE CULTURE AND UTILIZATION OF SEAWEEDS
VOLUME II

TABLE OF CONTENTS

REGIONAL SEAFARMING DEVELOPMENT AND DEMONSTRATION PROJECT RAS/90/002

27–31 August 1990
Cebu City
PHILIPPINES

Regional Seafarming Development and Demonstration Project
Network of Aquaculture Centres in Asia
Bangkok, Thailand

Hyperlinks to non-FAO Internet sites do not imply any official endorsement of or responsibility for the opinions, ideas, data or products presented at these locations, or guarantee the validity of the information provided. The sole purpose of links to non-FAO sites is to indicate further information available on related topics.

This electronic document has been scanned using optical character recognition (OCR) software. FAO declines all responsibility for any discrepancies that may exist between the present document and its original printed version.

TABLE OF CONTENTS

TECHNICAL RESEARCH REPORTS

- A review of the production technologies of tropical species of economic seaweeds. By **Gavino C. Trono, Jr.**

- Cultivation of temperate seaweeds in the Asia Pacific region. By **Wu Chao yuan.**

- Gracilaria culture in China. By **Chen Jia Xin.**

- Study of the intensive culture of Undaria on the coast of Brittany. By **R. Kaas & R. Perez.**

- Environmental aspects of seaweed culture. By **M. J. Phillips.**

- The mass culture of Dunaliella salina. By **Michael A. Borowitzka.**

- Various aspects of fundamental research, biotechnology and industrial transfer using microalgae. By **J. P. Dubacq.**

- Processing and extraction of phycocolloids. By **Ji Minghou.**

- Production, properties, and uses of alginate, carrageenan and agar. By **Olivier Barbaroux.**

- Marine algae utilization in food and pharmacology. By **Annette Alfsen.**

- Summary of international production and demand for seaweed colloids. By **David James.**

- Production, marketing and trade of seaweeds. By **Nirmala Richards-Rajadurai.**

A REVIEW OF THE PRODUCTION TECHNOLOGIES OF TROPICAL SPECIES OF ECONOMIC SEAWEEDS

TECHNICAL RESEARCH REPORTS

GAVINO C. TRONO, JR.

Marine Science Institute
University of the Philippines
Quezon City, Philippines

The world-wide increasing demand for seaweeds and seaweed products as items of food and raw material for the manufacture of industrial products as agar, carrageenan and alginate has been the main factor which has encouraged the development of production technologies of economic species of seaweeds. This paper is a brief review of the current production technologies for four tropical seaweed genera, namely, Eucheuma, Kappaphycus, Gracilaria and Caulerpa. The related production problems and needs are also described.

1. Mariculture of Eucheuma denticulatum/Kappaphycus alvarezii

Two species of carrageenophytes, namely, Eucheuma denticulatum and Kappaphycus alvarezii, are cultured in the Philippines, Indonesia, Western Central Pacific Islands and several other tropical countries. Both species are farmed using the same method of culture, the fixed bottom monoline and the raft method. E. denticulatum, however, is more strict in its farm ecology requirements than K. alvarezii. The latter can grow very well in sites where E. denticulatum are farmed. In contrast, E. denticulatum is not as productive in areas suited for K. alvarezii culture. A number of criteria are used in the selection of farm sites. These are water movement (current), water depth, bottom type (substrate), and presence of highly diverse marine communities where Eucheuma is present. Reef flats with good amount of water movement (current) which do not fully bare during extreme tides of spring characterized by high water transparency, and far from fresh water source are indicators that the area may be ideal sites for their culture. However, it is necessary that trial culture should be done first to determine the feasibility of the site for this purpose before any development of the area is done.

a. Fixed Bottom Monoline Method

The fixed bottom monoline method is the technique being used in the culture of the two species. It has many advantages over the other methods used in the past e.g. net method. It is cheaper and easy to install and maintain, although it is not as intensive as the net method. In this method, the stakes which are driven deep into the substrate are spaced 10 meters apart and at one meter interval in rows. The end of nylon monofilament line (180 lbs/test, about 10.5 meters long) is tied to one stake, stretched and the other end is tied to another stake in the opposite row. The monolines are constructed in such a fashion as to form plots or units of known sizes. Selected Eucheuma cuttings (50–100 gms) are tied to the monolines at 25–30 cm intervals using soft plastic tying material, i.e., soft plastic straw. The plants are allowed to grow to one kilogram or more in size before these are harvested. Depending on the growth rates, the crop may be harvested after two to three months. The whole plants are harvested and replaced by new cuttings.

b. Raft or Floating Method

In areas where space requirement for the monoline fixed bottom method is not available or where this method does not seem to work due to associated problems such as intense grazing and seasonality in growth, disease and changes in the degree of water movement brought about by monsoons the raft or floating method is used. The advantages of this method are: 1) grazing by bottom associated animals are minimized or eliminated because the plants are raised way out of reach of the grazers and 2) the plants, being near the surface of the water column, are exposed to more moderate water movement caused by waves. This method however is not recommended in sites exposed to strong waves.

The same principle used in fixed bottom monoline method is used except that the monolines to which the seedlings/cuttings are tied are attached to raft. Bamboo is the usual floating device used or if wood is used as frame of the raft, floatation materials such as pieces of styrofoam or empty plastic containers are used. In some areas, plastic bags filled with air are used as floating device. The raft is anchored to the bottom by means of nylon lines.

In order to maximize production per unit of raft, more intensive seeding is applied, i.e., the distances between lines and cuttings attached to monolines are closer. The size of the raft depends on the length of the frame materials. Aside from maximizing the number of plants on a raft, it has been observed that the adverse effects of more intense sunlight near the surface of the water column is offset by the slightly crowded spacing of the plants.

Eucheuma farming, like any other agricultural or fishery industry, has its share of problems which may adversely affect the productivity of the crop. The occurrence of these problems appears to be highly coincident with the seasonal changes in the ecological factors such as light intensity and water temperature regimes, nutrients and weather disturbances. These factors seem to be the predisposing conditions which result in the reduction or the complete loss of crops. Among these problems are "aging effect", negative growth rates, the ice-ice disease, weeds and epiphytes, grazing, and crop loss due to typhoon. These problems may be minimized if the farms are ideally located.

"Aging effect" in Eucheuma is manifested by the slowing down of growth with time which appears to be directly associated with condition characterized by high light intensity regimes. Morphological changes such as the general thinning of the branches especially towards the distal portions of the plants, the production of fewer branches, the general paling of plants and roughening of the thallus surface are the signs of this problem. These indicators appear about a month or so after planting but plants may recover if no further complications develop. However, if this poor condition progresses further it may result in very slow growth and the advent of the ice-ice disease may completely result in total loss of the crop. This syndrome is characterized at its early stage by the general paling and later the development of discoloration on portions of the branches of the plants which ultimately become whitish in appearance. The tissue at the affected portions becomes soft and eroded. Breaking of the branches takes place at these infected parts. In farm areas characterized by strong water movement, the plants easily break into pieces and are carried away by current. Past studies have also shown that the occurrence of the "disease" is preceded by or coincides with the production of tremendous biomass of other associated seaweed species and epiphytes. The occurrence of these blooms seems to be contributory to the predisposing conditions which result in the development of "ice-ice." In addition the incidence of this disease is preceded by low nutrient concentration. The tremendous amount of biomass (blooms) of associated species would have further depleted the nutrient supply available to the Eucheuma.

At present there is no known method in controlling the occurrence of ice-ice. To minimize loses, the crops should be harvested as soon as the disease appears. New batch of healthy plants should be used as starter seedstock. Weeding may help alleviate the effects of the predisposing condition of low nutrient supply to the crops but in instances where the other species develop tremendous biomass weeding becomes futile. Losses due to the effects of typhoons may be minimized by locating the farms in non-typhoon areas or reef areas not fully exposed to strong waves and currents during bad weather. In typhoon-prone areas, the crop losses may be minimized by harvesting these before the strong winds and waves hit the area. Thus a typhoon warning system is necessary. The effects of grazing may be minimized by the physical removal of the predators. However, it is impossible to control the seasonal grazing of big schools of rabbit fish (siganids). There is no known method of control for the predisposing conditions to "aging effect". Fertilization may partly solve the effects of low nutrient supply but will be very expensive. The use of "fertilizer blocks" has limited beneficial effects in open water farm sites for Eucheuma.

2. Production of Gracilaria

The production of agar producing seaweeds comes from three sources, namely, from gathering of drift materials and direct harvest from natural stocks, and cultivation. At present a large bulk of the seaweeds used for agar manufacture still comes from production from natural stocks. There is no available and accurate data on the contributions of agarophytes produced through culture but judging from the genera presently produced in different countries (Armisen and Galatas, 1987) which were imported by Japan in 1984, about 50% of the raw seaweeds processed into agar still comes from the production from natural stocks. The genera utilized in the international market for agar production are Gracilaria, Gelidium, Pterocladia, Gelidiella, Anhfeltia and Ceramium. Approximately 6,683 MT of agar were produced by 14 countries in 1984 (Armisen and Galatas, loc. cit.) about 48% of these amount were processed from Gelidium and Pterocladia, the other 52% from "other seaweeds" undoubtedly include other genera such as Gelidiella and Gracilaria. As far as we know today only the genus Gracilaria is being produced in commercial quantities through cultivation. In the first half of the 1980's, Chile, Brazil, Taiwan and the Philippines were the main suppliers of cultured Gracilaria to Japan. Recently, Vietnam, Indonesia, Thailand, Hawaii, etc. have applied culture techniques to Gracilaria production. Even at present a large portion of seaweeds produced by the Gracilaria producing countries still comes from local stocks. Gelidium and Pterocladia utilized mainly for the manufacture of bacteriological agar and agarose, so far as we are aware of, come from the gathering of natural stocks. Their commercial production through farming seems to be still a long way from realization. Thus, the production of most of these agarophytes is expected to be dependent still on their natural stocks for a long time to come.

2.1. Culture of Gracilaria

a. Considerations in the Selection of Species and Site for Culture

The following are important points to consider in the selection of species to be used and site for culture.

The species targeted for culture should have the following properties:

- It must be a fast growing species which can be propagated utilizing vegetative propagules (cuttings) or spores. Species with large and robust thalli are preferred because these can produce large amount of biomass within relatively shorter cropping periods.
- It must have high agar contents of good quality.

The above considerations therefore requires that the available species be screened. Comparative studies on their productivity should be conducted to determine the species to be selected. Because the properties of agar (gel strength, gelling and melting temperatures, amount of sulfate groups) differ among species it is terribly necessary that the correct name be applied. Thus the taxonomy of the species should be clarified. The names are indices to the kind and quality of agar the Gracilaria contains and are used as basis for determining the prices.

- The selection of sites is a very important factor to consider in the pond and field culture because this could be the primary factor for success or failure of the farming venture. In general, areas that support natural stocks of species to be cultured are good sites. If culture will be done in an area where no stock of the species exists, then one should select sites which have comparable ecological conditions as the site where the stocks are found. This will need the gathering of data on various parameters such as salinity ranges, nutrient levels (NO^{-1}_3, PO^{-3}_4), turbidity, and type of substrate: other ecological parameters such as degree of exposure to waves, depth of the water and accessibility are also included in the evaluation of sites.

Natural Gracilaria stocks are generally found in areas which are characterized by calm water, high nutrient levels, shallow areas with sandy-muddy substrates. Sites for field culture should be located in areas which are generally protected from waves. Gracilaria has fleshy and fragile thalli and therefore easily removed or broken by waves. Species which are generally found in commercial quantities grow quite well in slightly brackish and highly fertilized waters thus protected bays and lagoons are areas generally preferred by most species. In tropical areas, Gracilaria species with high potentials for culture are also found on reef and sandy flats to sandy rocky and wave-exposed areas.

b. Production of Seeds

The term "seeds" here refers to both the vegetative propagules (cuttings) and spores which can be utilized as planting materials. The importance of the availability of local as source of seed materials is emphasized. These seedstocks may come from natural stocks or those from cultivation. Gracilaria exhibits triphasic alternation of the generation consisting of the gametophyte, sporophyte and carposporophyte. The latter, however, is microscopic and is parasitic on the female gametophyte. Thus, the large somatic stage consists of the gametophyte and the sporophyte. The results of the studies on the populations of these two generations have shown that the sporophytes are generally more dominant than the gametophytes, i.e., these are usually larger in size and the population makes up the bulk of the biomass. It has also been shown that under pond culture conditions (per. com.) the alga may not develop reproductive stages. These information are relevant in the selection of the type of "seeds" to be used in culture.

Vegetative (cuttings) propagules

Healthy stocks are selected for this purpose. The stocks should have thalli which are fleshy and elastic in texture, dark reddish brown color, robust well branched with smooth and shiny surfaces. In addition these must be clean, free from dirt and epiphytes. The preparation of the "seeds" vary depending on the type of culture used and these are described in appropriate sections of this paper.

Spores as seeding material

Two methods are being practices in the production of sporelings from spores: natural spore-recruitment and induced spore-shedding in hatcheries.

- Natural spore recruitment

  The use of spores as seeding materials for the production of sporelings for culture necessitates the availability of natural stocks. In the natural spore recruitment method artificial substrates such as ropes, rocks and netting materials are used. Ropes and netting materials are generally preferred. The use of ropes is a proven technique in the West Indies. The ropes are anchored or tied to wooden stakes among the dense populations of Gracilaria. These are left in the area for about two weeks to allow the naturally shed spores to settle on them. The sporelings developing from the spores become visible after 3 to 4 weeks. The seeded ropes are then transferred to the culture sites for outgrowing.

- Hatchery production of sporelings from spores

  The production of sporelings from spores requires some skills in recognizing fertile materials. Fertile materials are selected from available stocks. Recognition of the fertile female materials is quite easy because of the highly recognizable presence of cystocarps. These fertile structures appear as elevated mammillate "bumps" on the surface of the thalli with dark colored contents. Cystocarps which had already shed the spores ("empty") are pale in color. In contrast the recognition of fertile sporophytic thalli is quite hard because the tetrasporangia are microscopic and do not form apparent recognised structures. The use of stereo-microscope is quite indispensable. The tetrasporangia appear as dark purplish microscopic spots on the surface of the thalli under low magnification. The presence of these structures, however, has to be counter-checked by the examination of sections of the suspected thalli under a compound microscope. The tetrasporangia are of the cruciate type and are embedded in the cortex of the thallus.

The hatchery production of sporelings requires land-based setup which may be sited some distance away from the outgrowing area. The setup was first used in Penang, Malaysia.

It is quite similar to those used in the seeding facilities for Porphyra and Laminaria although less sophisticated. It consists of a seeding tank with provision for control of water depth with an adjustable seeding material support structure. This structure consists of a wooden frame with monofilament netting material which can fit into the seeding tank. It is provided with mechanism so that its height from the bottom of the tank can be adjusted.

Various types of substrates can be seeded, e.g., pieces of gravel, shells or lines. These materials are placed at the bottom of the seeding tank. The use of lines as setting substrate requires additional structure, i.e., a frame which also fits the tank when laid flat on the bottom. The line may be monofilament nylon (90 lbs test as used in Malaysia) nylon braided ropes (ca. 3 mm diameter) or plastic tying materials. The "raffia line" is wound evenly to the raffia seeding frame. The frame with "raffia line" is then placed at the bottom of the tank.

Fertile material of Gracilaria are collected from natural stocks brought to the seeding facility. The moist materials are placed in containers such as styrofoam boxes provided with aeration holes to avoid stressing the materials which can affect the shedding and/or viability of the spores.

The fertile Gracilaria are then placed on the seeding support structure submerged in water in the seeding tank. The distance of the seeding materials from the seeding substrates (rocks, stones or raffia in frames) should be adjusted to ensure the uniform distribution and density of the spores. The seeding materials are left in the tanks for 2 to 3 days to allow the shedding of the spores.

The seeded materials may be left in the tank for another 1 to 3 days to allow the spores to germinate and completely attached to the raffia or substrates. In the case of Porphyra, the seeded lines are transferred to a nursery ground where the spores are allowed to grow to sporeling size before transferring these to the outgrowing plots in the open sea. The immediate transfer of the seeded "raffia" to the nursery ground leaves the seeding tank free for immediate reuse.

The seeded rope is transferred to a holding tank or of a nursery area while waiting for the spores to develop into sporelings.

Production and selection of highly productive seedstocks

The utilization of highly productive species/strains with high quality natural product is always a factor in the successful farming of Gracilaria or any crop for that matter. In species where it is easy to manipulate the individuals to be improved hybridization utilizing the gametes may be the normal and logical way of improving the seedstocks. However, in Gracilaria and other species where the technique in the manipulation of the sexual process to produce hybrids is not well known other methods may be used in selection.

One of these methods is through species/strain selection. Different strains/species present in a natural populations are selected, e.g., different species, various colored strains, morphologically different thalli. These different strains/species are then multiplied through cloning. Comparative eco-physiological studies are then conducted using these stocks. In situ studies on seasonality and production capacities of the various strains/species relative to changes in ecological factors as salinity, temperature nutrients and water movement are important in determining the field conditions which determine the productivity of the various strains as well as the seasonal aspects of reproductive states and capacities of the various forms.

Physiological studies to determine the range in tolerance of the various species/strains to the changes in ecological factors can be determined through the use of manometric techniques using a respirometer where one can accurately control the various factors. The photosynthetic/respiratory responses can be monitored under varying conditions of stress.

Analysis of contents and agar quality of the various strains is also an indispensable tool in determining the qualities of the various strains or species as basis for the selection of seedstocks.

c. Methods of Culture

Pond Culture

Although several species of agarophytes belonging to the genera Gelidium, Pterocladia and Gracilaria have been reported to be commercially produced through some form of farming in several countries, such as Japan, China, Republic of Korea, Vietnam, India and the Philippines, it is in Taiwan where the production of Gracilaria through pond culture has achieved a high degree of success. Here an average of 12,000 tons per hectare per year of fresh (300 ha) Gracilaria has been produced during the past few years (Chiang, 1981).

The genus Gracilaria is characterized by the alternation of three somatic generations, the sporophyte, the gametophyte and the carposporophyte stages. The last stage is microscopic and it is parasitic on the female gametophytes, thus the gametophytic and sporophytic stages are the macroscopic forms which are used as planting materials in the pond culture. Although the reproductive potential of Gracilaria through spores is high, vegetative propagation by cuttings is presently used in the pond culture because of the very high regenerative capacity of the plant and the simplicity of the method. However, "hatchery produced" seedlings from spores have been demonstrated to be superior in the open field culture of Gracilaria (Doty, 1986).

Out of the several species of the genus presently used (e.g. Gracilaria chorda, G. tenuistipitata, G. edulis, G. "verrucosa", G. lichenoides, G. compressa, and G. gigas), G. "verrucosa" is the most popular due to its ability to adapt to a wide range of ecological conditions in ponds, its higher production rates and better gel quality. The culture of Gracilaria started in 1962 in southwestern Taiwan. Production in ponds is primarily influenced by three ecological factors, namely salinity, light and temperature. High production is recorded during the months characterized by higher temperatures and growth is slow during winter. High light intensity experts adverse effects on the growth, therefore control of light conditions is practiced by adjusting the water depth in the ponds. Salinity of 15 to 24 ppt appears to be optimal for growth. The increase in salinity during the summer months is controlled by the addition of freshwater, thus farms need to be located near freshwater resources.

• Site Selection

The success in pond culture of Gracilaria is highly dependent on the selection of appropriate sites. The following criteria are recommended in the selection of sites for pond culture:

- the site should be located near seawater and freshwater sources;
- the area should be protected from strong winds;
- the pond bottom should be at or near the zero tide level;
- the pH of the water should be slightly alkaline. e.g. 8.2 to 8.7

Gracilaria is a euryhaline species and can grow in brackish water under a wide range of salinity. A salinity range of 15 to 24 ppt have been found to be optimal. Salinity rises during the sunny months due to evaporation losses reaching values as high as 35 ppt or drops to as low as 8 ppt during the rainy season were shown to be detrimental to the crop. The maintenance of optimal salinity in the ponds requires readily available freshwater and seawater supply. The ponds should be located in areas protected from strong winds because there is a tendency for Gracilaria to accumulate on the leeward side of the pond. The formation of thick heaps of Gracilaria at one side of the pond has adverse effects on the growth due to shading.

Water management is greatly influenced by the tidal changes in relation to the elevation of the pond bottom. Ponds located in areas where the bottom is at or a little above the zero tide level can easily be managed as water exchange is easy.

• Culture Ponds

The average size of ponds for the culture of Gracilaria is about one hectare or smaller. Smaller ponds are easier to manage than larger ones because in large ponds Gracilaria used to accumulate at one side due to the influence of winds. Pond management is also easier when Gracilaria is polycultured with shrimp and/or crab. Provision of entrance and exit gates facilitate proper water management.

The depth of the ponds vary from 50 to 80 cm. The bottom generally is of clayish loam, silty loam or sandy loam. It was observed that Gracilaria easily gets buried in ponds with sandy bottom due to the effect of wind. This problem, however, could be resolved by increasing the depth of the water during windy periods. In larger ponds wind breaks consisting of bamboo slots are installed perpendicular to the direction of the wind to prevent the seaweed being transported to one side of the pond.

• Culture Method

The following method is generally followed in the pond culture of Gracilaria. The ponds are dried for several days, water is then introduced. Healthy stocks are selected as planting materials. These are generally characterized by their elastic feel to touch, reddish brown color, brittle texture, they must have stout and well branched thalli and must be free of dirt and extraneous materials. The planting material is transported from its source to the pond site early in the morning to prevent its exposure to the sun. During long-distance transport it is frequently sprinkled with seawater and perforated bamboo or plastic pipes are inserted into the bottom of the heap to provide aeration. The plants must immediately be placed in the water of the pond upon arrival. The planting material is then cut into pieces and is broadcasted uniformly on the bottom of the pond. In Taiwan, stocking is usually made with 5,000 to 6,000 kg chopped Gracilaria per hectare in April.

• Pond Management

The water is maintained at a depth when the surface is approximately 30 to 40 cm above the heap of the algae. However, the depth is increased to cover the algae by 60 to 80 cm during the warm summer months to prevent a significant rise in the water temperature. Water depth is also increased during the cold winter months to avoid temperature drops below 8°C which is lethal to Gracilaria.

Frequent exchange of water is necessary to maintain the optimum temperature of water in the ponds. The water is changed in every two to three days. About 50 to 75% of the pond water is drained and replaced with fresh seawater.

Fertilization with either organic or inorganic fertilizers is done to enhance the growth of Gracilaria. In Taiwan, weekly application of three kilogram of urea per hectare was found sufficient. Fermented pig manure may be applied at a 160 to 180 kg per hectare dosage two to three days after the exchange of the water.

• Harvest and Post-harvest Activities

Under optimum conditions, the crop may be harvest 2 to 3 months after seeding. Cropping may be done every 30 to 45 days manually or by using scoop nets. The frequency of harvests is primarily dictated by the market price and the season. Approximately 30 to 40% of the biomass is harvested during each cropping. The crop is thoroughly washed in pond water to remove the silt, sand, pieces of shells and other extraneous materials, such as snails and other algae. The clean Gracilaria is spread uniformly on bamboo screens or plastic sheets for drying. An average wet to dry ratio of 7:1 is generally attained.

Standards set by the Bureau of Standards in Taiwan for the export of dried Gracilaria require that the product should not contain more than 1% of mud and sand, not more than 1% shells and not more than 18% other seaweed species. Moisture contents should not exceed 20%.

Dried Gracilaria is then packed into sacks of 100 kg weight for export or sold to local processing plants. Ten to twelve metric tons of dried Gracilaria are produced in a hectare of pond.

• Polyculture with Shrimp and/or Crab

Polyculture with shrimp (Penaeus monodon) and/or crab (Scylla serrata) is mainly done in Ping-tung prefecture in southwestern Taiwan. Stocking material for a hectare of farm consists of 4,000 to 5,000 kg of Gracilaria, 5,000 to 10,000 crab and 10,000 to 20,000 shrimp. Crushed trash fish and snails are generally used as feed for the crab. Crabs are harvested after three months, the shrimp often after four to seven months. Survival rates as high as 80% for crabs and 80 to 90% for shrimp has been documented making this polyculture one of the most profitable aquaculture method methods in Taiwan. The net income from polyculture has been proven to be three times as much as from monoculture.

In the Philippines a group of 40 fish farmers in Iloilo are also producing Gracilaria in their multi-crop fish farms. They also use cuttings as seedstocks. They do not use fertilizer as in Taiwan but only allow daily water exchange by tidal flow to ensure adequate nutrient supply for the seaweed. The ease in water management is enhanced by siting the bottom of the ponds at or just slightly above the 0 tide level. One of the main problems in the pond culture of Gracilaria is water management. Ponds are located away from both the fresh water and sea water sources and where the level of the bottom of the ponds is way above the 0 tide level, water changes becomes a major problem. In such ponds water can only be facilitated during extreme high tides. Maintenance of adequate nutrient levels as well as control of water temperature thus become a major problem. Another problem encountered in pond culture using large size ponds is the tendency of the Gracilaria to accumulate at the leeward portion of the ponds due to the influence of wind generated waves. The piling of a large of biomass is one portion of the pond results to shading. It also impedes the circulation of water which adversely affects nutrient supply. Provision of wind breakers as the "bamboo blocks" and "net blocks" in the ponds perpendicular to the direction of the prevailing winds, as practiced in Taiwan, has proven to be effective and cause increased production compared to ponds without them.

The development of blooms of other algae such as filamentous blue greens and greens is one of the major problems in the Philippines. These algae may totally displace Gracilaria or if not, they become so mixed with Gracilaria it becomes impossible to separate them resulting in a very low quality of the dried materials. The problem of blooms of epiphytes and other weeds has been placed under control by the introduction of grazers such as Tilapia and milkfish. However, the size and number of these grazers must be controlled otherwise these may consume the Gracilaria. The other countries at present engaged in pond culture of Gracilaria are Vietnam, Thailand, Indonesia, China (in Hainan Province), and Hawaii.

Field Culture

There are several methods now being utilized in the field culture of Gracilaria. The "seeds" used in these various methods are cuttings or sporeling produced from spores.

• Fixed bottom long line method

In this method of culture three-strand polyethylene ropes 5 to 8 mm in thickness and 5 meters long is generally used. Other materials such as coir or abaca ropes may be used as substitute. In the West Indies where the mariculture of sea moss (Gracilaria) is most successful the use of both sporelings produced from spores and cuttings are utilized as "seeds" in the fixed long line method as well as in the raft method.

The seeding of long lines using cutting consists of untwisting the rope and inserting bunches of cuttings between the strands of the rope, the seedlings passing twice or three times through the rope. This method insures that the cuttings are securely tucked in placed. The seeding of the ropes is done under the shade where the seedlings are placed in basin of sea water to prevent the cuttings from drying up.

The support system from the long line consists of wooden stakes driven into the ground. These are usually arranged in rows, the distance between stakes in the row is about one meter while the distance between rows of stakes would vary between 4 to 5 meters or longer. One end of the seeded rope is tied to a stake, stretched tightly and the other end tied to the opposite stake in the next row. In the West Indies two seeded ropes are usually tied to a pair of stakes.

The same technique is applied for ropes seeded with spores. In Malaysia, unbraided plastic raffia seeded with hatchery produced sporelings was used as long lines. In India longer ropes are used using additional stakes as support are provided to prevent the ropes from sagging to the ground. The distance of the seeded ropes from the ground vary depending on the depth and clarity of the water as affected by tidal changes. This method of field culture is being utilized in the West Indies, Burma, India, Brazil and Ceylon.

• Chilean method

The field culture method used in Chile is simple but has proven very successful. The anchoring system for the seedstocks (cuttings) consists of plastic bags one meter long, 0.1 mm thick and 4 cm in diameter. The plastic bag is filled with sand and the two ends are knotted. Five bunches of seedstock are tied to the same side of the sand-filled bags by rubber bands. The seeded bags are arranged in rows on the substratum and are positioned in such a way that the bag serves as an anchoring weight. The middle of the cuttings are weighted by the bag against the surface of the substrate with the tips of the cutting jutting free of the anchoring units.

The use of rocks as anchoring units for the cuttings was also found to be effective. However, both the use sand-filled bag and rocks as anchoring materials for cuttings was efficient in sites which are not exposed to strong surges or waves. Evaluation of the efficacy of this system showed that more than 60% of the biomass could be lost due to removal of thalli by strong surges. Using rocks as anchor system was observed to be more adversely affected than that using sand-filled bags; rock-anchored cuttings are easily dislodge from the substrate.

• Improvement of substrates

The method could only be utilized in areas where natural beds are found. The introduction of artificial substrates such as rocks, shells, bamboo or wooden stakes, etc. in the site provides additional favorable substrates for the spores to settle or fragments of thalli to attach. Most of the commercially important species of Gracilaria (beds) are found in shallow bays and coves where the substrate is generally particulate (sandy-muddy). The survival and success of spores to grow is greatly enhanced by the availability of solid substrates. Results of studies on the influence of solid substrate on biomass production had shown that production more than doubled in portions of the beds where solid substrates have been introduced.

• Raft method

The raft method is popularly used in West Indies in areas where bamboos are available. The raft generally measures 2 × 4 meters in size. The seeded long line are also utilized. One end of the seeded rope is tied to the shorter bamboo frame, stretch tightly and the other end fixed to the opposite side of the raft. The distance between ropes vary but about 12 to 14 lines may be planted to one raft.

In India the use of coir ropes fabricated into a network of 7 cm mesh size was used on a 2×2 m raft. The same method of seeding was utilized.

Variation from this method has been developed in China. Pieces of ropes about 70 cm long seeded with Gracilaria cuttings are hung horizontally on the low fixed raft or vertically along a long line floating raft.

2.2 Management of Natural Stocks

a. Important considerations in the utilization of natural stocks as source of biomass

The production of agarophytes from natural stocks is very much influenced by both the seasonal factors as well as by the harvest pressures exerted on them during the preceding cropping season. Because their growth cycles are highly influenced by environmental conditions and by man's exploitative activities their production is therefore unreliable. These are prone to over-exploitation. The need to manage and conserve their stocks is of prime importance in order to sustain or enhance further their productivity and prevent their over-exploitation.

The design of a sound management scheme for the natural stocks of commercial agarophytes depends primarily on the available information on the various aspects of their biology, such as reproduction and growth cycle, growth rates, their regeneration and recruitment capacities, productivity and the influence of environmental factors on the biomass production potentials of the stocks. The above information are necessary in the formulation of guidelines for the management of the natural stock of the target species. These information can provide answers to questions such as where the species is abundant, how much to harvest per unit area, when to harvest, how many times (cropping intervals) can the stocks be harvested in one season, what kind of harvest method is best for the species. The gathering of these basic information on the species to be managed requires basic skills in methodologies for field sampling and data gathering. Under management the production of stocks can be safely forecasted. This information is most important in quoted contracts which may be entered into by the farmer, fisherman, or exporter.

Thus, it is of prime importance that any plan to exploit natural stocks of seaweeds must be preceded by intensive biological studies to determine their seasonality in biomass production, reproduction, regeneration and recruitment. These information are necessary in determining the best possible time to harvest and the amount of harvestable stocks without diminishing their production capacities.

b. Requisite for the rational exploitation of natural stocks

Under a free-for-all situation, there is a tendency for the resource users to over-exploit the resources especially where there is a prevailing demand for the produce. The literature is replete with records of loss of the resource due to over exploitation. Thus, it is necessary that the commercial exploitation of natural stocks of seaweeds or any resource be preceded by biological studies which shall be the basis for their management. The following are the required biological studies which should be done in coming up with information as basis for the management of the stocks:

Inventory and assessment of stocks

The inventory and assessment of stocks are initial studies which should be done in areas where the exploitation of the stocks has not started, to know the kinds (species) potentially available for development, where and when these species are abundant, how much biomass is available for harvest and the behavior and responses of the stocks to certain degrees of exploitation.

The need to know the real identities of the different species is very important because unlike other resources, e.g., fish, crustaceans, etc., the kinds and quality of agar vary with species. Thus, it is very important that the taxonomy of the species comprising the stocks be known. In addition the quality of the hydrocolloid (agar) be defined, characterized or evaluated as the price of the produce is determined by the quality of the extractable agar from them. In the world market for agar the name of the species and in case of Gracilaria the information on the source of the dried raw material are important because these reflect the differences in the properties of these agar, e.g., there are the Gelidium, Pterocladia, and Gracilaria agar. The Gracilaria from Chile for instance is more high priced than Philippine Gracilaria because it contains high quality agar. Thus, the names applied to these produce serve as basis for the pricing of the produce. The price is generally based on the moisture content and purity and quality of the agar (gel strength, melting and gelling temperatures, viscosity and amount of sulfate group).

The information on the abundance and distribution of the resource in space and time may be gathered through biomass sampling of the stocks. There are available methodologies which have been applied and these may slightly differ depending on the behavior of the resource. However, the transect quadrant method is generally applied especially in situations where the stocks are not homogeneously distributed in space. The size of the bed is first delineated and permanent transects are marked. The orientation of the transects is generally related to certain ecological gradients, e.g., depth, wave exposure. Biomass sampling are generally done on a monthly basis along the transects; the size of the quadrant vary from 0.25 to 1.0 m^2, and the number of quadrants to be sampled along the transects may also vary depending on the size and homogeneity of the bed, the time and efforts required but most important is the reasonableness of the amount and kind of data for statistical analyses i.e. the more samples to be gathered, the more reliable the data will tend to be.

The amount of loose (drift) biomass should also be monitored to come up with reliable data on the total biomass production of the bed.

Data on the biomass production recorded for a period of one year will indicate the annual productivity and seasonality in the production of the stocks. Additional year round of data will make the information on the stocks more reliable as basis for management. In most stock assessment works where the target species or group of species and their distribution are known the main concern in sampling is the production data.

The size of the bed must be known so that the potential total production of stocks can be determined. This information is vital in determining how much of the stocks should be harvested without unduly diminishing their productivity. Using the production data from the samples, total production of the bed may be projected/calculated by multiplying the biomass data (e.g., g/m^2) by the size of the bed. The accuracy of the method is much improved if regular and repeated sampling on the stocks are done through time.

Additional source of information on the seaweed production in the area can be gained through interviews with market vendors and seaweed gatherers. Initial interviews may be done in local open markets where seaweeds are sold. Seaweed vendors are good source of information on the kinds of species, amount they sell, source of seaweed stocks, the supplier and the approximate number of gatherers. Seaweed gatherers are good source of primary data on production. They can be easily identified by inquiring from local officials in the area. Data on gathering sites, number of gatherers, the gathering season and output per unit effort, may be acquired from this source. Estimate of local production can then be made and counter-checked with the data on potential biomass production of the beds or collecting area.

The seasonal variation in the reproductive/fertility states of the stocks should also be known. The fertility of the stock may be determined by randomly collecting 50 or more thalli and the number of the vegetative and fertile thalli are determined. This is usually expressed as % fertility. This information is relevant in the scheduling of harvesting/cropping periods. The recruitment capacities of stocks is generally influenced by their states of fertility especially for those species where recruitment is largely dependent on the production of reproductive cells (spores). Cropping or harvesting should be scheduled some time before or after the peak of fertility of the stocks in order not to unduly interfere with the recruitment process. This, however, may not be relevant on species where production is mainly based on vegetative means (cuttings, fragments). Some stocks of Gracilaria, for instance, have been reported to be purely vegetative (Rueness et al., 1987). Pond cultured Gracilaria in Northern Philippines have been observed to be purely vegetative the whole year round (per. comm.). In cases where recruitment is primarily based on vegetative means certain amount of the seedstocks is retained in the bed for next season's cropping. This amount may be equivalent to the amount of biomass produced in the bed during it's lowest production period.

In addition to these basic biological studies harvesting experiments should be carried out to determine the production capacities and the effects of different harvest pressures and methods on the regeneration of the stocks. The information in the capability of the stocks to regenerate to their former level of production after trial cropping/harvesting shall be the basis for determining the harvest schedules during the cropping season.

Development and application of management scheme for the stocks

The application of a management scheme on natural stocks has been shown to significantly improve the total production of the beds. In Chile, the annual production of the Gracilaria in Lenga Cove located in San Vicente Bay increased from 80 MT to 600 MT after the application of a management programme (Poblete and Inostroza, 1987). It is apparent from their studies that the strict application of a management scheme, had improved the production ecology of the bed resulting in a 7.5-fold increase over normal production.

In general the formulation and application of a management scheme for the natural stock of seaweeds may follow the following stages/steps. Variation from this scheme may be necessary to suit certain biological characteristics of the species. The basic considerations include:

• The seasonal changes in the annual productivity of the stocks

The information on changes in the annual productivity of the stocks are derived from the monthly biomass measurements done on the bed. It provides information on the total amount of biomass available for cropping and the season when cropping/harvesting may be done. In addition to the information on the annual productivity of the stocks, the seasonal variation in the amount of agar contained in the crop is also considered in the scheduling of the harvest. High quality crop is obtained when cropping is done during periods when its agar contents is high.

• Determination of the amount of biomass to be left after cropping

The amount of biomass left after the first cropping is very important in determining the amount of biomass available for the next cropping season. It is a rule of thumb that this minimum amount to be left in the bed to serve as "seeds" for the next cropping season should not be less than lowest biomass recorded during the year. The amount of biomass available for harvest will be the difference between the total amount of biomass available in the bed during its peak production period and the minimum biomass during its depressed period of growth.

• Determination of the harvest schedule

How often should the harvest be done during the peak production season of the stocks? The harvest regimes can be determined from information on the regenerative capacity of the stocks, e.g., from the results of studies on different trial harvest pressure. The schedule of subsequent harvests is determined by the period within which the stock can recover its original biomass after the first harvest.

• Control of the amount of biomass to be harvested

The amount of biomass to be harvested during each harvest regime should not exceed the amount of biomass available for cropping. The amount of biomass available for cropping is the difference between the maximum amount of biomass during its peak production period and the minimum amount of biomass during the stress period of growth. Thus, it is necessary that the number of fishermen should be limited and the amount of crop each should be allowed to harvest must not exceed his share of the available biomass for cropping during each of the cropping period.

• Protection of the recruitment and regeneration processes

This is a very important consideration because the continuity of the stocks depends on these processes. The approach may differ depending on the biological characteristics of the species. For stocks which depend on the regeneration of biomass through vegetative structures such as holdfast, cuttings or fragments, and underground thalli, the protection of these structures may be done by the application of harvest methods which would cause the minimum harm to these regenerative structures. For those stocks where recruitment and regeneration processes depend on both the reproductive cells and the vegetative structures, the timing of the harvest so as not to impede or adversely affect recruitment and the method of harvest which will have minimal destructive effects on the regenerative structures are important considerations. Thus, harvesting should not be done during peak fertility of the stocks.

• Socio-economic consideration in managing the resources

The fishermen/seaweed gatherers should be organized into production groups such as cooperative. Only the bonafide members have the right of access to the resource and the amount of harvest each of the member is allowed to crop is determined by his fair share of the available biomass for cropping. The legal basis for enforcing these regulations can be easily achieved through the rules promulgated by the local government or by the cooperative's established rules/regulations. Peer pressure among the members is a strong factor which may be applied to the members. The management of the cooperative is done by the selected members. A portion of the earnings of the members is channeled back to the cooperative for management support. Technical assistance should be extended to the cooperative by the concerned government agencies.

3. Production of Caulerpa

3.1. Pond Culture

The development of a new area into Caulerpa ponds consists of several stages, namely, site selection, pond construction, planting of the ponds, maintenance of the culture, harvest and post-harvest activities. Fishponds with marginal production are usually preferred because initial investment for their conversion to Caulerpa ponds is low and usually the location of these unproductive fishponds generally fits the ecological requirements of Caulerpa culture, that is, they are far from sources of freshwater and pollution sources.

a. Site Selection

The success in the culture of Caulerpa depends primarily on the selection of a good site. The following ecological factors have to be considered when electing sites for pond culture of Caulerpa.

a. The site must be far from sources of freshwater such as rivers and streams. Caulerpa is a purely marine stenohaline alga and will die even in slightly brackish seawater. The salinity should not be lower than 30 ppt.
b. The elevation of the pond bottom must be at or just a little above the zero tidal level. This is necessary in order to enhance proper water management in the ponds. Frequent water change is necessary for the growth and development of Caulerpa.
c. The site must be protected from the destructive effects of wind and waves. A buffer zone of mangroves and/or coral reef is necessary.
d. The substrate must be loamy-muddy. However, very deep, soft mud must be avoided.
e. Sites with acidic soil should be avoided. Caulerpa will not grow in areas characterized by low pH.
f. The area must be near an unpolluted source of seawater supply. Caulerpa is consumed fresh, thus it must be grown in areas free from both domestic and industrial pollution. Bacterial contamination of the crop should be avoided. Caulerpa may also absorb pollutants such as heavy metals and toxic chemicals which it can accumulate with deleterious effects to the consumers.
g. Existing saltwater ponds can be used for Caulerpa culture. Some framers stock milkfish in Caulerpa ponds as a secondary crop.

b. Pond Construction

The maintenance of good water quality necessary for good growth of Caulerpa through proper water management is dependent on the proper design of the ponds. The traditional layout of ponds for milkfish and shrimp production does not provide the necessary water exchange required in Caulerpa culture.

Caulerpa ponds may be divided into compartments of 0.10 to 0.25 hectare and should incorporate a flow-through design; each of the compartments should be provided with individual entrance and exit gates positioned in such a way that the water could easily be changed and circulated during the draining and flooding process. The flow-through design is important to facilitate frequent and complete water change necessary in maintaining high nutrient level in the seawater required by the seaweed for rapid growth and development. Peripheral or diversion canal may also have to be provided to divert runoff water from the ponds during rains to avoid drastic lowering of salinity in the ponds which is detrimental to the crop.

c. Planting of the Ponds

The ponds should be drained to a depth of 0.3 meters to facilitate planting. During the early development of the culture, broadcasting was used to "seed" the ponds with Caulerpa cuttings. However, this technique was found to be inefficient because the "seeds" were not uniformly distributed on the pond bottom and resulted in the uneven growth of the crop.

Planting is done by burying into the mud one end of a handful of Caulerpa cuttings at about one meter interval. Uniform planting is facilitated with the use of lines as guide or the planted spots are marked by pieces of bamboo. After planting, the ponds should be flooded to a depth of about 0.5 to 0.8 m. Flooding should be done slowly to prevent the newly planted cuttings from being uprooted and carried away by the current. The newly planted ponds must be inspected a day or so after planting and the unplanted areas should be planted to ensure uniform growth. The pond water should be changed only several days after planting to make sure that the cuttings are already well rooted and could not be carried away by water currents.

An initial stocking rate of 1000 kg per hectare under favorable weather conditions can produce a good crop in about two to three months.

d. Water Management

Proper water management is a key factor in the successful pond culture of Caulerpa. Ideally, the pond water must be changed every three to four days at the start of the growing period in order to avoid strong water currents which may uproot the seedlings. The frequency of water changes should be increased to every other day at about the third week after planting especially when the plants start to form a thick growth on the pond bottom. Frequent water exchanges provide fresh supply of nutrients for the normal growth and development of Caulerpa, thus, it will eliminate the need for fertilizer application.

In general the water in the ponds must be maintained at a depth where the Caulerpa is visible from the surface of the water. Thus, the depth of the water in the pond would vary depending on the transparency of the pond water to provide enough light for photosynthesis. However, adjustments in water depth should be made to avoid perimeter dikes from collapsing during spring tides when the tidal amplitudes are extreme. During rainy days the pond water should also be maintained at a slightly greater depth to reduce the possibility of a dilution below 30 ppt. Caulerpa will die when the salinity goes below this level and the entire crop may be lost. After heavy rains the pond water should be immediately drained and replaced by fresh seawater to ensure that the salinity is maintained at or above 30 ppt.

Fertilization may not be necessary as long as frequent water exchange can be made. However, fertilizer has to be applied especially one or two weeks before the harvest, when a large crop has already been produced and when the plants appear to be pale in color (that is light green or yellowish). The sufficient rate of fertilization is about 16 kg per hectare. Nitrogenous fertilizers have produced very good results. The plants regain their healthy green color a few days after application. The fertilizer may be broadcasted, but past experience has shown that wrapping the fertilizer in many layers of gunny or plastic sacks and suspending these in strategic places in the pond at a level where the bags are just about half submerged in water, produces very good results. The fertilizer should be applied right after water in the pond has been changed for several days after the fertilizer has been applied.

Weeding is an important activity which should be done regularly to remove other seaweed species and associated organisms growing in the pond. Weeds compete with Caulerpa for space, light and nutrients. The weeds and the associated organisms should be removed before they take over as dominants. The presence of the weeds results in decreased production and low quality of the product and adds extra labor cost to sort them out before the product is sold in the market.

The dikes and gates of the ponds must be continuously maintained to effect efficient water management. This is especially critical during the monsoon season when strict and efficient water management is required to avoid extreme dilutions due to heavy rains.

e. Harvesting and Post-Harvest Activities

Depending on the growth rate of the plants the crop may be harvested two months after the initial planting, when the plants had already formed a relatively uniform carpet on the pond bottom. The plants at this stage are of high market quality, light grass-green in color, soft and succulent in texture. Older plants though high in biomass are of lower quality because they are tougher in texture and their basal portions are pale or colorless. The paling of the basal portions of the fronds are caused by self-shading when the plants became older and form very thick carpet.

Harvesting is done by uprooting the plants from the muddy pond bottom. More crops can be produced during a growing season if partial harvesting is done leaving a sizeable amount of 20–25 percent of the crop in the pond to serve as seedstock for the next crop. Harvesting should be done in such a way that the leftover of the crop is more or less uniformly distributed in the ponds. Large vacant areas of the pond bottom should be replanted to ensure uniform crop stand. This practice has drastically reduced production costs by savings made in labor costs for replanting. The sizeable amount of seedstock left in the pond also results in a much shorter growing period and the farmers in Mactan, Cebu claim they can harvest every two weeks after the first harvest during the optimal growing season (dry season). Studies have shown that the algae could triple its initial weight after two months (Trono & Denila, 1987).

Harvested seaweeds are thoroughly washed in seawater to remove the mud and other debris. They are then sorted, unsuitable thalli and other seaweed species are removed. The clean seaweed is placed in bamboo baskets lined with banana leaves or other seaweeds such as Sargassum. The baskets are filled with clean seaweeds, then topped with leaves or Sargassum and finally covered with plastic sack which is secured by lacing its margin to the basket. The baskets are placed under the shade where they are allowed to drip before transporting them to the market. The product can stay fresh for four to five days.

Caulerpa for export to other countries (such as Japan) is shipped as a fresh product or in brine-cured or salted form. The seaweed is first thoroughly washed several times in seawater. Then thalli of good quality are selected. The clean seaweed is first completely drained of water, packed in styrofoam boxes provided with aeration holes on the upper side or cover of the box, taped and sent to its destination by air cargo. A large portion of Caulerpa exported to other countries is either brine-cured or salted. The latter two forms can be kept for longer periods and may be transported by surface cargo.

3.2. Open Lagoon Farming

Open lagoon farming of C. lentillifera have been successfully tried in some parts of the Philippines. The selection of the site for the farm is a primary consideration which would determine the success or failure. Several criteria are considered in the selection of sites for farming. Caulerpa is a stenohaline marine alga. It can not survive or successfully colonize brackish areas where salinity is lower than 28 ‰ so that lagoons located away from sources of fresh water are preferred. The water depth must be at least 1–2 feet during low tides. Shallow lagoons are usually characterized by turbid waters, thus areas which are deep should be avoided because light may become the limiting factor to growth. Sites characterized by good amount of tidal flushing is preferred because renewal of nutrients is facilitated as well as minimize sedimentation which may cover the plants cutting off of light needed for photosynthesis. The presence of a rich algal community is a good indicator that the site can support Caulerpa farming. Sites with barren substrates should be avoided. The substrate should be loamy muddy although areas with very deep soft bottom should be avoided.

The area should first be partly cleared of other seaweeds and seagrasses before planting. The method of planting follows that applied to pond culture. One end of a handful of Caulerpa cuttings are buried into the muddy lagoon bottom. The seedlings are planted at 0.5 m intervals or closer. The development of the seedlings are monitored at the start to ensure that these are not covered or overgrown by other seaweeds species. Weeding will thus give them a headstart to colonize the area.

Harvest may be done after a month or so when the stocks has developed 50% cover on the substrate. Thinning or partial harvest is done to provide enough stocks for the succeeding crops.

References

Armisen, R. and F. Galatas. 1987. Production, properties and uses of agar. In D. J. McHugh (ed.) Production and utilization of products from commercial seaweeds. FAO Fish. Tech. Pop. (288): 1–57.

Barrales, H. and A. Pizarro. 1986. Field Assessment of Two Methods for Planting the Agar-Containing Seaweed, Gracilaria, in Northern Chile. Aquaculture: 59: 31–43.

Bird, K.T. 1987. Gracilaria Cultivation in the Caribbean. Paper Presented at the 1987 Caribbean Aquaculture Trade Expo. in Puerto Rico. 8 pp.

Bird, K.T. 1988. Agar Production and Quality from Gracilaria sp. strain G-16: Effects of Environmental Factors. Botanica Marina 31: 33–39.

Bird, K. T., M. D. Hanisak and J. Ryther. 1981. Chemical Quality and Production of Agar from Gracilaria tikvahiae Grown in Different Nitrogen Enrichment Conditions. Botanica Marina 24: 441–444.

Chiang, Y. M. 1981. Cultivation of Gracilaria (Rhodophycophyta, Gigartinales) in Taiwan. Proc. 10th Intl. Seaweed Symp.: 569–574.

Daugherty, B. and K. T. Bird. 1988. Salinity and Temperature Effects on Agar Production for Gracilaria verrucosa Strain G-16. Aquaculture 74: 1–9.

De Zaixso, A.L.B. 1987. Gracilaria verrucosa in Golfo Nuevo, Chubut, Argentina. Biological parameters and environmental factors. Hydrobiologia 151/152: 239–244.

Doty, M. S. 1986. Estimating farmer returns from producing Gracilaria and Eucheuma on line farms. Monografias Biologicas, 4: 45–62.

Doty, M. S. and V.B. Alvarez. 1973. Seaweed Farms: An Approach for the U. S. Industry. In: Marine Technology Society 9th Annual Conference Proc: 701– 708.

Doty, M. S. and V. B. Alvarez. 1975. Status, problems, advances and economics of Eucheuma farms. J. Mar. Technol. Soc. 9(4):30.

Guerin, J. M. and K. T. Bird. 1987. Effects of Aeration Period on the Productivity and Agar Quality of Gracilaria sp. Aquaculture 64: 105–109.

Guerrero, R. D. 1989. Producing Gulaman in Ponds for Export. Fishbites. Agribusiness Weekly. July 14–20: 12. Lin, M. N., G. Y. Lin and T. L. Huang. 1979. Preliminary Report on the Improvement of Gracilaria Farming. Agriculture 2(3): 22–31.

Naylor, J. 1976. Production, trade and utilization of seaweeds and seaweed products. Fisheries Tech. Paper No. 159. FAO, Rome.

Neisch, A.C. 1978. Developments in the culture of algae and seaweeds. pp. 395–402. In. T.V.R. Pillay and W. A. Dill (eds.). Advances in Aquaculture. Fishing News Books Ltd., Farnhein, Surrey, England.

Poblete, A. and I. Inostroza. 1987. Management of a Gracilaria natural bed in Lenga, Chile: A Case Study. Hydrobiologia 151/152: 307–311.

Raju, P.V. and P.C. Thomas. 1971. Experimental Field Cultivation of Gracilaria edulis (Gmel.) Silva. Botanica Marina. 14: 71–75.

Rueness, J., H. A. Mathisen and T. Tananger. 1987. Culture and field ovservations on Gracilaria verrucosa from Norway. Botanica Marina 30: 267– 276.

Santelices, B. J. Vasquez, U. Ohme and E. Fork. 1984. Managing wild crops of Gracilaria in Central Chile. Hydrobiologia 116/117: 78–89.

Sijian, L. 1986. Experiments of Picking Spore and Raising Seedling of Gracilaria tenuistipitata. Jour. Zhanjiang Fish. Coll. 1: 31–34.

Sijian, L., L. B. Bensong, Z. Shufang, L. Bingsin and J. Zhenying. 1986. The Experiment of Gracilaria tenuistipitata fixed to Sporeling Rope with Float Raft in Tidal Zone. Jour. Zhanjiang Fish. Coll. 1: 35–38.

Smith, A. 1986. A guide to seamoss cultivation in the West Indies. Carribean Conservation Association Publication. 19 pp.

Smith, A. H., Nichols, K. and McLachlan, J. 1984. The cultivation of seamoss Gracilaria in Sta. Lucia, West Indies. Hydrobiologia 116–117: 249–251.

Tachanavarong, S. 1988. Gracilaria Culture in Thailand. In: Report on Training Course on Seaweed Farming. ASEAN/SF/88/GEN/6: pp. 136–141. FAO Publication.

Thomas, P. C. K. Rama Rao, and K. Subbaramaiah. 1975. Changes in natural growth of Gelidiella acerosa (Forsskal) Feldmann et Hamel in an exploited population. Botanica Marina 18: 241–243.

Trono, G. C. Jr. 1974. Eucheuma farming in the Philippines. Univ. of the Philippines Natural Science Research Center Publication. 13 pp.

Trono, G.C. Jr. 1981. The Present Status of Production and Utilization of Seaweeds in Asia. In: G.C. Trono, Jr. and E.T.G. Fortes (eds.) Report on the Training Course on Gracilaria Algae. SCS/GEN/81/ 29: 44-44. FAO Pub., Manila.

Trono, G.C. Jr. 1981. Field Culture of Gracilaria and other Species. In: G.C. Trono, Jr and E.T.G. Fortes (eds.) Report on the Training Course on Gracilaria Algae. SCS/GEN/81/29: 51–56.

Trono, G.C. Jr. 1981. Natural production of commercially important seaweed species. In. G.C. Trono, Jr. and E.T. Ganzon-Fortes (eds.) Report on the training course on Gracilaria algae. SCS/GEN/ 81/29: 45–46.

Trono, G.C. Jr. 1986. Seaweed Culture in the Asia-Pacific Region RAPA Publication 1987/8. Regional Office for Asia and the Pacific. FAO of the United Nations, Bangkok Thailand. 41 pp.

Trono, G.C. Jr. 1986. Seaweed Culture in the Asia-Pacific Region. RAPA Publication 1987/8: 15–18. FAO, Bangkok.

Trono, G.C. Jr. 1987. Studies on the pond culture of Caulerpa. Phil. Jour. Sci., Monogr. 17: 83–98.

Trono, G.C. Jr. 1988. Production of Economically Important Seaweeds through culture and Harvesting of Natural Stocks. In: Report on the Training Course on Seaweed Farming. ASEAN/SF/88/GEN/6: 59–70. FAO Publication.

Trono, G.C. Jr. and E.T. Ganzon-Fortes. 1988. Philippine Seaweeds. 330 pp. National Bookstore Inc., Metro Manila, Philippines.

Trono, G.C. Jr. (1989, in press). Inventory and assessment of natural stocks of marine macrobenthic algae. In: Proceedings of Seaweed Research Training and Workshop for Project Leaders. 6 pp. Jointly sponsored by the Marine Science Institute, College of Science, University of the Philippines at Quezon City, and the Philippine Council for Agricultural Resources Research and Development, Los Banos, Laguna, Philippines.

Uyenco, F., L.S. Saniel and G.S. Jacinto. 1981. The "ice-ice" problem in seaweed farming. Proc. International Seaweed Symposium 10: 625–630.

FAO. 1983. World Seaweed Industry and Trade. Joint ADB/FAO (SCS-INFOFISH) Market Studies. Vol. 6. 30 pp. SCS/DEV/83/26. FAO, Manila.

CULTIVATION OF TEMPERATE SEAWEEDS IN THE ASIA PACIFIC REGION

WU CHAO YUAN

Institute of Oceanology, Academia Sinica
7 Nanhai Road, Qingdao, China

In 1980 the total world production of seaweeds was estimated at about 65,000 tons (ADB/FAO Market Studies, 1983). More recent figures indicate that the total production of cultured seaweeds in the Asia-Pacific region represents more than 90% of the world's (Csavas, 1985). In this region, four countries, China, Japan, Republic of Korea and the Philippines, are principally engaged in the cultivation of six economic species. It was also estimated that the world seaweed production contributed 20% to the total volume of the global aquaculture production (Csavas, 1985).

Farming of sea plants, specifically algae, has a relatively short history, perhaps three hundred years. Scientific farming of algae started only some 30 years ago. Porphyra was one of the algae which has long attracted man's interest. The Orientals appreciate the Porphyra so much that natural production was unable to meet demand. Undoubtedly the Orientals many years ago must have tried hard to produce the much appreciated Porphyra. However, it was not until the early sixties that Porphyra cultivation began to be made on a truly scientific basis. Another alga greatly appreciated in the Orient is the Laminaria, especially L. japonica. This seaweed has been appreciated by the Chinese people for at least fifteen hundred years, but it was not until the early fifties that the Laminaria was successfully produced by artificial cultivation on floating rafts. These two cases show that, even with present-day scientific knowledge, it is still not easy matter to domesticate a wild alga into a real crop plant that can grow better than their wild relatives. So far only a few algae can be regarded as truly marine crop plants. These would include Eucheuma, Undaria, Gracilaria, Macrocystis and Caulerpa besides the above mentioned Porphyra and Laminaria.

Cultivation of Laminaria

Laminaria Japonica is one of the several species successfully cultivated in commercial scale. Starting from the mid-fifties, the following seven crucial problems concerning the artificial cultivation of Laminaria had been solved:

1. The floating raft method of artificial cultivation. This method is characterized by three important processes. The first is the spore collection and sporeling cultivation process. The second is the setting-up of the floating raft for cultivation. The superiority of the raft method lies in maintaining the plants at the desired water level. This is one of the keys to successful cultivation. The third is the sporeling transplantation. This is a crucial process ensuring appropriate density for the growth of the plants.

2. Method of low temperature culture of summer sporelings. Spore collection takes place in early summer instead of autumn. Gametophytes and young sporelings are cultured under controlled low temperature conditions. In late autumn, the sporelings are taken off to the open sea. This method enhances the production by 50%, since the summer sporelings have an advantage of two to three months' growth (Tseng, 1955).

3. It has been found that Laminaria cannot grow well in places where the total nitrogen content is lower than 5mg/m^3, but in fertile places, for example, the total nitrogen content is as high as 20 mg/m^3, the plants can grow fast and reach commercial standard within several months. Fertilizing the sea is, however, a difficult activity. In the mid-fifties, the clay bottle method of fertilizer application was devised to take advantage of the porous nature of earthenware. Clay bottles containing fertilizer solution were hung under the raft. The porosity of the bottles effectively controlled the outflow of the fertilizer which became available to the plant in the immediate vicinity. Loss into the open sea was also minimized. In the early sixties, the clay bottle method was replaced by plastic bags punched with minute pores, allowing the nutrient solution to leach out slowly. Later, experiments showed that with large farms hundreds of hectares in area, application of the fertilizer solution by spraying to the open sea can be generally adopted (Tseng, 1955).

4. Southward transplantation. L. japonica is native to the cold temperate coastal regions along northern Japan and Siberia. Experimental results showed that, although the optimal temperature for Laminaria growth was 5–10 °C, growth was still good enough at 13 °C; even at 20 °C, a frond of 1–2 m was still able to attain some growth. Based on the above experiments, Chinese phycologists conducted an experiment in 1956 on the cultivation of the Laminaria at Gouqi Island, Zhejiang Province. The results of the experiment fully confirmed their postulation that Laminaria of commercial standard can be cultivated along the Eastern China sea coast. Production in the area now accounts for one third of China's entire production (Tseng, 1957).

5. Genetical studies and breeding of new strains. Genetic studies showed that natural populations of the Laminaria now under cultivation in China are genetically mixed in nature and are considered to possess a high level of hybridity. In the sixties, three varieties were bred, one with broad frond, one with long frond and one with thick frond. In the seventies, two new varieties with high iodine content and high yield were bred, which answered better the demands of the iodine industry of China (IOAS and QIMF, 1976).

6. Pathogenic diseases. In recent years three kinds of pathogenic diseases in cultured Laminaria have been recognized. One of these is the malformation disease of summer sporelings in green house. The disease is characterized by the death of oogonia and the malformation of the young sporophyte. The cause of this disease is the presence of hydrogen sulfide which is produced by sulfate-reducing and hydrogen sulfide producing saprophytic bacteria (Wu et al., 1976). The other well-documented disease is the frond twist disease of cultivated Laminaria on floating rafts. The diseased plants have abnormally twisted fronds with swollen stipes and shortened holdfasts. The disease is caused by a kind of mycoplasma-like organism. Another kind of disease found in the greenhouse is the rot disease of summer sporelings. This is characterized by the detachment of the sporelings from the sporeling-rope and the rot of the blade and the stipe. It has been found that the alginic acid decomposing bacteria Pseudomonas is the cause of the decay of the holdfast by enzymatic action of arginase, finally resulting in the detachment and loss of the sporelings (Wu et al., 1982).

7. Frond tip-cutting method. Based on the study of the transportation and accumulation of assimilate devised in the late fifties. By this method the distal part of the frond, sometimes as much as one third of the entire frond, are cut off at certain time to improve the lighting condition of the frond. Such measure improves the conditions for the growth of the frond and enhances the quality of the product. The cutoff distal part of the frond will be cast off anyway under the natural condition; this part is not good for food but is good raw material for the algin industry. By taking such measures, the increase of production generally amounts to about 15% (Wu et al., 1981).

Since the mid-fifties, the above achievements for enhancing the production and improving the quality of Laminaria have been successfully devised one after the other. Now, commercial cultivation of Laminaria is being practiced on the China coast from Dalian of the north to Fujian Province of the south. In the 1978–1979, more than 18,000 hectares of farms were engaged in the commercial cultivation of Laminaria, and about 275,500 tons in dry weight of this alga were produced.

Being the 'home' of Laminaria japonica, Japan had been the principal producer of this much desired seaweed, producing mainly from the nature 120,000 tons in wet weight annually in the late seventies. Natural production is not steady and fluctuates greatly. Artificial production was initiated in the early fifties, two methods attempted being the stone-planting technique and the blasting of reefs (Hasegawa, 1976). Improvement in production was, however, not promising, and production was unable to meet the demands. Since 1968, the so-called forced cultivation method has been employed, and the output has increased from 30 tonnes in 1969 to over 7,500 tonnes in wet weight in 1974, amounting to 16% of the natural production on reefs (Hasegawa, 1976).

Cultivation of Porphyra

Both Japan and China have a long history of the cultivation and utilization of Porphyra. Commercial cultivation of Porphyra in Japan was initiated more than 300 years ago by the primitive method of inserting bundles of bamboo twigs, called hibi, for collecting spores. In China, more than 200 years ago the simple 'rock clearing' method of cultivation was devised by mechanically clearing seaweeds from the rocks in early autumn. This was done just before the mass liberation of the spores. The surface of the rock would then provide the substratum for the spores to attach and grow. The whole process is simple, but people have to depend upon nature's mercy to give them spores. This condition is similar to the Japanese 'bamboo-hibi planting' method. Up to the early fifties the source of the spores had been a mystery to the phycologists. In the early fifties, Drew discovered the conchocelis as a stage in the life history of Porphyra. Later on, both the Japanese and the Chinese phycologists (Tseng & Chang, 1954), who independently discovered the missing link, the conchospore. The shell of Meretrix sp., was found to be an excellent substrate for conchospore. It was not until the '60's that, with the introduction of the artificial collection of conchospores, the commercial cultivation methods became truly modernized. In China, the intertidal semifloating raft method for growing the leafy Porphyra from conchospores is preferred over the fixed pillar method. Conchospore-seeded nets are first allowed to stay in the intertidal zone until the leafy Porphyra appear and then are transferred to deeper areas. In Japan, with the innovation of the cold-storage net and the use of floating nets, Porphyra production increased steadily. P. tenera and P. yezoensis are the two principal species cultivated, although six species are grown commercially. In 1981, the Japanese farmers produced 34,000 t (dry weight) of Porphyra. In China 9,987 t of Porphyra was produced in 1981, while the Republic of Korea has been produced 8,000 t annually these past few years.

Cultivation of Undaria

The other seaweed now under commercial cultivation and qualified to be called a marine crop is Undaria. Today Undaria pinnatifida is the main species under cultivation. Undaria undariodoides and Undaria peterseniana are cultivated to a minor extent. In Japan, the cultivation of Undaria has been developed only in the sixties when the natural resources were not sufficient to cover the ever-increasing demand for this alga. At present, production of Undaria through culture is estimated to be 91,000 t (wet weight) in Japan (1981), 100,000 t (wet weight) in the Republic of Korea these few years, and several thousand tons in China in the eighties each year.

The cultivation of Undaria consists of the following three stages:

1. Collection of zoospores and growing of sporelings. Collection of zoospores begins at about April to June when the plants become fertile. The matured sporophylls are kept in a dark moist container for several hours to induce the mass discharge of the spores. These spores attach themselves to substrates and develop into male and female gametophytes. The fusion of the gametes results in the formation of zygotes which give rise to young sporophytes. The favourable temperature for the growth of gametophytes and the formation of oogonia and antheridia is at 15–25 °C (Li et al., 1982). In China and northern Japan the seeded ropes were directly cultured in the open sea under a raft where the young sporelings are allowed to grow to about 2–3 cm long.

2. Outgrowing of the plant. The outgrowing of sporelings starts in the autumn when the water temperature is about 20 °C. The sporeling ropes are cut into 5–6 cm long pieces, which are inserted and tied in the twists of the cultivation ropes. The cultivation ropes with the attached sporelings are set into the sea. The depth of the water where outgrowing is done ranges from 0.5–5 m depending on the transparency of the water. The range of optimum temperature is at 5–10 °C (Zhang, 1984). The plants are harvested when they reach a length of 0.5–1 meter. In areas where the growing season is long, several harvests can be made from the same ropes. Since Undaria has an early short-growing season, maturing much earlier than Laminaria, it is often mixed-planted with Laminaria in China. In that case, Undaria does not interfere with the growth and maturation of Laminaria, which is harvested in June (Tseng, 1981).

Productivity of Laminaria, Porphyra and Undaria

Seaweeds are potentially very productive. Porphyra yezoensis, Laminaria japonica and Undaria pinnatifida are believed to be the potential food products of the tidal zone. The commercial production of these benthic macroscopic marine algae reaches 110 gm^{-2} for Porphyra, 1,500 gm^{-2} for Laminaria and 150 gm^{-2} for Undaria (Wu, 1984). As these seaweeds are cultivated under more or less artificially controlled conditions, it is likely that the production will be raised even higher under certain favourable conditions. The spectacular rates of primary production are found in all these three algae. Under the cultivated condition in North China, the annual primary productivity of P. vezoensis is calculated to be 270 g m^{-2}, that of L. japonica 2,200 g m^{-2} and U. pinnatifida 160 g m^{-2} (Wu, 1984). The raft method of cultivation maintains the seaweeds at the desired depths, which generally ensures a light-saturated rate of photosynthesis on clear days to enhance productivity. On the other hand, the low respiratory rates as well as low light compensation points especially at low temperatures are considered as another reason to save heat energy, resulting in a high productivity, especially in case of Laminaria (Wu et al., 1984).

References

1. Annon., 1985. Yearbook of Fisheries 1985. Fisheries House (Japan), Tokyo, pp. 514 (in Japanese).
2. Csavas, I., 1985. Problems of Inland Fisheries and Aquaculture. A.P.O. Symposium on Fishing Industry, Nov. 12–18, 1985. SYP/VII/85. Tokyo.
3. Hasegawa, Y., 1976. Progress of Laminaria cultivation in Japan. J. Fish. Res. Board Can., 33:1002–1006.
4. Li, H.J., Tian S.M., 1982. The influence of temperature on the growth and development of the gametophytes of Undaria pinnatifida (Harv.) Sur. Transactions of Oceanology and Limnology, 2:1–8 (in Chinese).
5. Section of Seaweed Genetics and Breeding, Institute of Oceanology, Academia Sinica and Qingdao Institute of Marine Fisheries, 1976. The breeding of new varieties of Haidai (Laminaria japonica Aresh.) with high production and high iodine content. Scientia Sin., 19:243–252.
6. Tseng, C.K., Chang, T.J., 1954. Studies on Porphyra. I. Life history of Porphyra tenera Kjellm., Act. Bot. Sin., 3:287–302.
7. Tseng, C.K., Sun, K.Y., Wu, C.Y., 1955 a. On the cultivation of haidai (Laminaria japonica Aresch.) by summering young sporophytes at low temperature. Acta Bot. Sin., 4:255–264.
8. Tseng, C.K., Sun, K.Y., Wu, C.Y., 1955b. Studies on fertilizer application in the cultivation of haidai (Laminaria japonica Aresch.). Acta Bot. Sin., 4:255–264.
9. Tseng, C.K., Wu, C.Y., Sun, K.Y., 1957. The effect of temperature on the growth and development of the Haidai (Laminaria japonica Aresch.). Acta. Bot. Sin., 6:103–130.
10. Tseng, C.K., 1981. Commercial Cultivation. In the Biology of Seaweeds edited Lobban and Wynne, 1981, Blackwell Scientific Publications. pp. 690–692.
11. Tseng, C.K., Fei, X.G., 1987. Macroalgal Commercialization in the Orient. Hydrobiologis, 151/152: 167–172.
12. World Seaweed Industry and Trade. Joint ADB/FAO (SCS-INFOFISH) Market Studies. 1983, vol. 6. 30 pp. SCS/DEV/83/26. FAO, Manila.
13. Wu, C.Y., et al., 1979. On the malformation disease of Laminaria sporelings. Oceanol. Limnol. Sin., 10:238–250.
14. Wu, C.Y., Chen D., Li, J.J., 1982. On the diseases of cultivated Laminaria japonica. Proceedings of the Joint China-U.S. Phycology Symposium, pp. 211–220.
15. Wu, C.Y., Zheng, S.Q., Tseng, C.K., 1981. Tip-cutting of fronds as a means of increasing production in Laminaria aquaculture. Xth International Seaweed Symposium Proceedings, Walter de Gruyter & Co., Berlin, New York 1981. pp. 637–642.
16. Wu, C.Y., Wen, Z.C., Peng, Z.S., Zhang, J.P., 1984. A preliminary comparative study of the productivity of three economic seaweeds. Chinese J. of Oceanol and Limnol.
17. Zhang, D.M., Miao, G.R., Pei, L.Q., 1984. Studies on Undaria pinnatifida. Hydrobiologia, 116/117:263–265.

GRACILARIA CULTURE IN CHINA

CHEN JIA XIN
UNDP/FAO Seafarming Development
and Demonstration Project
Bangkok, Thailand.

1. Introduction

A number of agarophytes, including Gracilaria, Gelidium and others, have been used in China as marine vegetables or traditional medicinal herbs for over 1000 years. However, these seaweeds have became an industrially important raw material for processing agar only some decades ago.

Agarophytes in China are mainly represented in three genera of Rhodophyta, Gracilaria, Porphyra and Gelidium. Among >30 species of agarophytes Gracilaria vermucosa, G. tenuistipitata, Gelidium amansii, Porphyra haitanensis are the major ones. (Table 1, Plates 1 and 2). In addition, other red seaweeds, such as Pterocladia sp. Ceilidiella sp. and Ceramium sp. are often collected and mixed with the main agarophytes mentioned above and used for producing agar.

Table 1. Main Agarophytes in China.

Genera	Species	Genera	Species
Campylaephora	C. crassa	Gracilaria	G. rubra
	C. hypnaeoides		G. tenuistipitata (*)
Ceramium	C. boydenii		G. vermucosa (*)
	C. japonicum	Grateloupia	G. turuturu
	C. kondoi	Gymnogongrus	G. flabelliformis
Gelidium	G. amansii (*)	Hypnea	H. boergesenii
	G. crinale		H. cervicornis
	G. divaricatum		H. charoides
	G. pacificum	Pachymenia	P. carnosa
Gracilaria	G. articulata	Pachymeniopsis	P. elliptica
	G. bursa-pastoris	Porphyra	P. haitanensis (*)
	G. chorda		P. yezoensis (*)
	G. gigas (*)	Pterocladia	P. tenuis
	G. lichenoides (*)	Solieria	S. mollis

* Commercially important species

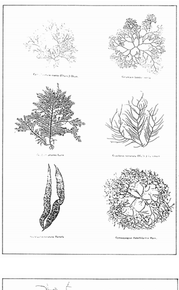


Plate 1. A number of Agarophyte species.

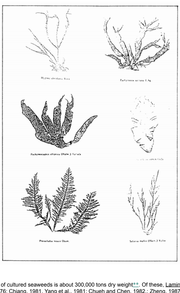


Plate 2. A number of Agarophyte species.

China is a major producer of cultured seaweeds. The total annual production of cultured seaweeds is about 300,000 tons dry weight(**). Of these, Laminaria and Porphyra account for 200,000 – 250,000 tons and 20,000 tons respectively. Gracilaria production is about 5,000 tons per annum (Shang, 1976; Chiang, 1981, Yang et al., 1981; Chuen and Chen, 1982.; Zheng, 1987). Laminaria in China is a main marine vegetable and raw material for extracting iodine, mannitol and alginate. Porphyra is also a popular marine vegetable. But in recent years some phycologists have observed that a considerable quantity of Porphyra thalli obtained from the later harvest during the season can be used for processing agar. The latter croppings have less edible value.

At present Gracilaria and Porphyra are the most important raw materials for producing agar. Although Gelidium has long been considered as the best raw material for processing agar, it is not the ideal cultured species because of its slow growth and low yield. On the other hand, Gracilaria is easier to farm. It is expected that a higher output can be obtained in farming conditions. Shang (1976) reported that the average productivity of dry Gracilaria in Taiwan ponds was 7 to 12 t ha^{-1} year-1. A few years later Chiang (1981, p. 573) observed that 16–43 t ha^{-1} year^{-1} could be expected. So, it is believed that there will be a substantial development of Gracilaria culture in China to meet the increasing demand of agar market.

In the present review we shall first discuss some general ecological characteristics of Gracilaria sp. which are especially important to its commercial production and subsequently review the farming practices developed for the species.

(**) Weights of seaweed production provided refer to dry weight only

2. Biology of Gracilaria

Gracilaria vermucosa is the most common species in China. It grows fast and has high agar content. Following is a discussion on the influence of the various environmental factors on the release and germination of spores and growth of thallus of the spores.

2.1 Influence of environmental factors on spore release

Both carpospores and tetraspores are released naturally into seawater after their maturation. Experiment showed that the maximum quantity of spores is released at 8–10 am., gradually decreasing thereafter. The minimum quantity is released at 10 pm. to 6 am. of the following day, after which the next maximum will take place. Besides the diurnal changes of releasing rhythmicity, the released quantity of spores also depends on ambient environmental factors. (Zheng, 1987).

2.1.1 Desiccation

In general, a mature Gracilaria is taken out of seawater and kept in a shady spot for 2 to 4 hours (air temperature 15–25 °C), the tetraspores or the carpospores will be released if the plant is dipped in seawater again. Table 2 gives the different quantities of tetraspores or carpospores released at different durations of desiccation, or removal from the seawater.

Table 2. The relationship between the quantity of tetraspores and carpospores released and desiccation time.

Time (hr.)	0.5	1	2	3	4	5	6
Tetraspores	887	1011	3033	1921	1904	1904	782
Carpospores	201	226	686	683	458	477	421

Source: Zheng, 1987.

2.1.2 Seawater temperature

Experiments have shown that the highest number of spores are released at 20–25 °C (Table 3). According to field surveys, the reproductive season of Gracilaria is between June to August in northern coastal provinces or between March to May in southern China. During these seasons, the natural seawater temperature is 20–25 °C. The experimental results coincide with natural reproductive seasons (Zheng, 1987).

Table 3. The relationship between released quantity and seawater temperature.

Temperature(°C)	8–10	15	20–22	25
Tetraspore	88	518	2925	1525
Carpospore	522	998	1343	824

Source: Zheng, 1987

2.1.3 Specific gravity of seawater

When mature plants were kept in seawater of different specific gravities, those in seawater of lower specific gravity would release spores earlier than those kept in water of higher specific gravity. If the plants are put in seawater with an obviously low specific gravity (<1.005), the released spores will swell and even break up due to osmosis caused by the low salinity so that most of them would not complete normal germination. In order to obtain good results in the collection of spores, the optimum specific gravity range of 1.015 (19.0 –20.2 ppt) to 1.020 (25.5 – 26.9 ppt) should be observed (Zheng, 1987).

2.2 Influence of environmental factors on germination and growth of the spores

Gracilaria spores just released into seawater, measure around 30 um in diameter and vary with species. Tetraspores are slightly bigger than carpospores. For example, the tetraspores of G. tenuistipitata have a diameter of 24–36 um, and carpospores 23–40 um. Soon after release, the spores will attach to substrates and start final cleavage of cells. The germination and growth of spores are also influenced by ambient environmental conditions such as seawater temperature, light intensity, salinity, etc. (Zheng, 1987).

2.2.1 Seawater temperature

To examine the germination and the growth of the spores those attached to slides for 12 hours were moved to containers with sterilized seawater enriched with 1 ml of 1 M KNO_3 and 1 ml of 0.1 M KH_2PO_4 per litre of seawater medium, and incubated with a light intensity of 400 Lux, photoperiod of 10:14 for different periods of time (Zheng, 1989). The results are shown on tables 4 and 5.

Table 4. The effect of temperature on carpospore disc size (um) after germination.

Time (days)	Temperature (°C)				
	7	10	15	20	28
10	39.6×39.6	42.9×42.9	46.2×46.2	46.3×46.3	42.9×42.9
20	39.6×39.6	49.5×49.5	52.8×52.8	59.4×59.4	49.5×42.5
30	46.2×46.2	59.4×59.4	59.4×59.4	56.1×56.1	56.1×56.1
40	56.9×46.5	62.7×59.0	69.1×62.7	75.3×75.9	72.6×59.4
50	56.9×46.5	66.0×59.4	66.0×66.0	95.7×82.5	99.0×82.5

Source: Zheng, 1987

Table 5. The effect of temperature on tetraspores disc size (um) after germination.

Time (days)	Temperature (°C)				
	7	10	15	20	28
10	39.6×39.6	36.3×36.3	39.6×39.6	36.0×36.0	39.1×39.1
20	39.6×39.6	42.9×42.9	49.5×49.5	42.9×42.9	42.9×42.9
30	46.2×46.7	62.7×62.7	62.8×62.8	52.8×52.8	52.8×52.8
40	52.8×49.8	69.3×62.7	75.9×61.9	75.9×66.0	75.9×66.0
50	49.5×42.9	66.0×59.0	95.7×82.5	95.9×85.0	99.0×82.5

Source: Zheng, 1987.

The results illustrate that both tetraspore discs and carpospore discs need a seawater temperature higher than 15 °C for their growth. If the temperature is below 15 °C, even if all other environmental conditions are suitable for their growth, they would survive but grow very slowly (Zheng, 1987, pp. 234– 235).

2.2.2 Light intensity

Light intensity is one of the most important factors that influence the germination and growth of spores. When the light intensity is stronger, the rate of germination and growth of spores are higher within 3000 Lux. If the spores attached to slides are kept in a dark place they will die in 20 days. The experimental results are shown on Table 6.

Table 6. The effect of light intensity on the spore disc growth (um) after germination.

Light intensity (LUX)	Time (days)			
	10	15	20	25
3000	69	78	93	112
1500	50	63	85	104
200	40	48	60	76
DARK	poor	poor	poor	-

Source: Zheng, 1987

2.2.3 Specific gravity of seawater

Although Gracilaria plants prefer to inhabit estuarine areas, their spores are unable to withstand seawater with low salinity. If the spores attached to substrate are put in seawater with a specific gravity below 1.010, (12.5–13.7 ppt) their cells swell up due to the absorption of water into the cells from ambient environment. The colour of the pigments in the cells would change from red to pale, and the spores will die eventually. Experiment proved that the optimum specific gravity of seawater for germination and growth of spores range from 1.018 (23.0–24.2 ppt) to 1.025 (25.5–26.9 ppt) (Zheng, 1987).

2.3 The effect of environmental factors on growth of Gracilaria thallus

The effects of environmental factors on Gracilaria thallus are similar to that on their spores, but not entirely the same. For instance, as mentioned above, spores kept in seawater with a specific gravity below 1.010, will break up and die, but the thallus can grow very well in the same conditions. In view of this, ambient environmental factors required by Gracilaria thallus must be studied.

2.3.1 Specific gravity of seawater

Gracilaria is a group of euryhaline seaweeds. Under natural conditions, the specific gravity in which the plant can grow out ranges from 1.005 to 1.026 (5.2–38.1 ppt). Experiments and field surveys have shown that the optimum specific gravity is 1.010–1.020 (11.3–30.1 ppt) where freshwater regularly flows in (Zheng, 1987).

2.3.2 Seawater temperature

Gracilaria is also an eurythermal plant which can grow at 5 to 30 °C. Optimum temperature varies with species. For example, the optimum temperature of G. vermucosa is 15–25 °C. They can be found during May to August in northern China, but in south China only in winter and spring. In summer, the growth of Gracilaria is almost completely stopped in the south until late autumn when the water temperature drops below 25 °C and the seaweeds will resuscitate again.

Field surveys have shown that the optimum seawater temperature of G. tenuisipitata, a species mainly distributed in Guangdong and Hainan Island, is identical with G. vermucosa. When the water temperate is 30 °C, its diurnal growth rate measures 0.1–0.2 cm/day but as the temperature continues to fall to 28 °C, the growth rate increases to 0.4–0.5 cm/day. When the temperature is from 15–25 °C, growth rate can be higher than 1 cm/day.

2.3.3 Light intensity

The growth of Gracilaria requires a high light intensity. It has been shown that growth rates of the seaweeds vary when they are planted at different depths of water (table 7 and 8) (Zheng, 1987, pp. 238–239).

Table 7. The growth rate of Gracilaria at different water depths.

Depth (cm)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
L_0 (cm)	22.0	22.5	27.3	15.3	19.5	27.7	19.8	12.8
L_t (cm)	27.0	28.0	28.7	16.0	20.5	28.5	18.8	10.7
L_t-L_0 (cm)	+5.0	+5.5	+1.4	+0.7	+1.0	+1.5	-1.0	-2.1
L_t-L_0/L_0 x 100 (%)	+2.3	+2.4	+0.5	+0.5	+0.5	-0.5	-0.5	-1.6

Source: Zheng, 1987

L_0 - initial length; L_t - terminal length in 10 days;
Mean water temperature - 17 °C
Mean specific gravity of seawater - 1.020 (25.5–30.1 ppt)2
Transparency of seawater - 3m

Table 8. The photosynthetic intensity of Gracilaria in different water layer (O_2 mg/L).

Depth (m)	Control	0 (**)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	
1 (*)		8.25	11.20	9.77	9.19	9.10	8.96	8.00	8.72	7.68	7.64
5 (*)		8.25	10.90	10.50	10.50	9.24	9.10	8.24	8.16	8.00	7.12
Mean		8.25	11.06	10.23	9.84	9.17	9.03	8.42	8.24	7.84	7.38

Source: Zheng, 1987.
(*) 1 and 5 are same experiments run on different date.
(**) Seawater without seaweeds.

Table 8 illustrates that the Gracilaria can grow well at a water depth less than 1 m deep where the seawater transparency is around 3 metres. If the seaweeds are planted in seawater deeper than 3 m not only do they stop growing but start rotting as well.

Values shown on Table 8 refer to dissolved oxygen in seawater collected in a bottle from different water depths where Gracilaria is located. The figures point that Gracilaria exposed to the maximum light intensity has also more intense photosynthetic activity. As the plants are located beneath 3 m depth, their respiratory intensity will exceed the photosynthetic intensity, which explains the finding that the content of dissolved oxygen in the seawater of the experimental groups was less than that of the control group which is without Gracilaria in it.

3 Farming

China has more than 30 years' history of farming Gracilaria. According to the specific biological characteristics of the seaweeds, different methods of collecting spores and farming thalli have been studied and practiced. This includes (1) collecting natural spores, (2) artificial outdoor collection of spores, or (3) indoor collection, (4) Mud flat culture, (5) floating raft culture and (6) pond culture.

3.1 Rearing of seedling

3.1.1 Outdoor collection of spores

The procedure involves 4 steps: selection of site, preparation of substrate, collection of parent plants (tetrosporophyte and/or carposporophyte) and collection of spores.

1) Site selection

A suitable site for collection of spores should be an intertidal flat area with harder bottom and clear seawater with a specific gravity range of 1.010–1.025 (12.5–33.4 ppt). A large spherical dwarf dam of 20–30 um high is made at the selected site to store seawater after ebb tide.

2) Preparation of substrate

Cheap substrates like stones, shells or broken corals can be used. These substrates have a clean surface for easy attachment of spores. If the substrate is a stone, each block should weigh about 0.5 kg, the total amount is about 600 tons stones per ha. For shell, 120 tons per ha. is sufficient. The substrate is spread on the selected site. In recent years, artificial fibers, nylon, polyethylene ropes or nets have been used to collect spores. The texture of these materials is good, but the cost is higher. Used or worn fishing nets can be used as a cheaper substrates.

3) Collection of parent plants

The parent plants must be fully mature with dull red-brown colour and without rotted spots on seaweeds body. As a fully mature plant, their sporangia are easily seen on the entire surface of the plant body.

4) Treatment of parent plants

Parent plants are washed with clean seawater to get rid of mud or other matters and allowed to air dry on bamboo curtains for 2–4 hours until irregular contractions appear on the plant surface. At this time, the seaweeds can be spread in a selected site with substrate. The quantity of parent plant required is about 300 kg per ha.

As soon as the parent Gracilaria are planted in seawater, they release a great quantity of spores into the seawater. The spores will settle down on the substrate in one day. Under natural conditions, the germination of spores is very fast. They will turn into dish-shaped thalli in 5 days.

Another method is to put the desiccated seaweeds into a vat and stir them vigorously with a stick to stimulate release of spores into seawater. About 2 hours later, the seawater containing a huge quantity of spores can be sprayed into a selected site.

3.1.2 Indoor collection of spores

The main steps followed in indoor collection of spores are similar to those in outdoor collection. The only difference is that the spores attached to substrate will be kept in indoor tanks for rearing until they grow into young plants.

3.2 Culture methods

3.2.1 Mud flat or intertidal culture

The main feature of this culture method is that the spore collection and farm sites are usually the same. In southern China, in late autumn or early winter, young Gracilaria can grow up to 5–6 cm long as they enter a period of faster growth rate. At this stage, the substrate to which young Gracilaria are attached are kept in lines on the bottom at an interval of 30–40 cm which will serve as a walk way. The routine management practice involves removal of miscellaneous seaweeds, collection of herbivorous gastropods and so on. Women and children often do it. In a normal season, 1500 kg (dry) of Gracilaria can be harvested.

3.2.2 Floating culture

The method has been adapted from kelp farming. In a suitable season, such as, January in southern China or May in the northern part, young seaweeds, both collected from other fields or reared in indoor tanks, are pulled up from substrate and inserted into ropes called "seeding rope" which are made of palm thread or artificial fiber. In each rope of 20 m length 200 pieces of seaweeds 10 cm apart can be inserted. The seeding ropes are then fixed on floating raft. Three months later, the seaweeds will reach a length of over 1 m and can be harvested. The yield can reach about 3000 kg (dry) per ha.

3.2.3 Pond culture

Pond culture of seaweeds has been adapted by Taiwan's phycologists and farmers since the 1960s. Before 1962 agarophytes were very scarce in Taiwan, and had to be imported. Phycologists and framers tried to rear the agarophyte Gracilaria in fish pond with milkfish. Unexpected good results were obtained so that many farms began to change the main cash crop from milkfish to Gracilaria. At present, Taiwan produces 12000 tons of Gracilaria (fresh weight) annually from 300 ha of ponds (Chiang, 1981).

The stock seaweeds are cut into pieces and spread in the fish pond at a density of (5–8 t of fresh thalli) per ha. Chemical fertilizer or pig manure is applied regularly. Every 30–45 days, most parts of the seaweeds can be harvested. The rest of the body is continually left in the ponds as stock. The harvesting period lasts six months from June to November in the northern part of China.
This method is being used in the southeast region owing to lesser inputs and higher production.

3.2 General comments

Although satisfactory results have been obtained with Gracilaria through several culture facilities there have not been any great advances in production similar to Laminaria or Porphyra farming. The main reason for this is lack of balance between production cost and market price. The lower market price is inhibiting the development of farming Gracilaria.

In recent years Gracilaria farming has become a popular industry owing to the increasing demand from the agar processing industry. A main production zone for Gracilaria has appeared in Southern China including Guangdong, Guangxi and Fujian provinces where seawater is warmer and rich in nutrient suitable to growth of Gracilaria plants. Liu (1987) reported that there are 4–5 species (G. vermucosa, G. tenuistipitata, G. gigas and G. bursa-pastoris) which are supplied farming species. His experiments and investigation have shown that it is possible to obtain an average yield of 2–3 tons ha^{-1}. He suggested that the acreage under farming of Gracilaria can be expanded to 6700 ha in Guangdong Province to produce 15000 tons (dry) of high quality Gracilaria.

Technical progress and advances in farming Gracilaria will further reduce the production cost and improve product quality. The following three suggestions are made to improve the culture production and utilization of this agarophyte:

1. Selection of suitable species for farming. High priority should be given to selection of species with faster growth rate and higher agar content and quality.
2. Adequate measures should be taken to protect natural stocks of Gracilaria to prevent over-exploitation of natural stock.
3. Polyculture of finfish and shellfish with Gracilaria offers several advantages. For example, the seaweeds belonging to autophytes can improve the quality of water contaminated by cultured animals; Gracilaria is a superior fodder for abalone which has a higher price in the world market. Gracilaria farming can supply abalone farms with the abalone food, while abalone farming would also help to promote agarophyte farming.

References

Chiang, Y. M. 1981. Cultivation of Gracilaria (Rhodophycophyta, Gigartinales) in Taiwan, Proc. Int. Seaweed Symp., 10:569–574.

Chuen, C. T. and C. C. Chen. 1982. Seaweed economics. In: R. T. Tsuda and Y.M. Chiang (Editors). Proceedings of Republic of China United States Cooperation Science Seminar on Cultivation and Utilization of Economic algae. Univ. of Guam Marine Laboratory, Mangilao, Guam, pp. 9–16.

Liu, S. J. 1987. Distribution, present production status and future of Gracilaria in Guangdong Province. Sci. and Tech. of Fisheries, 1:14–15.

Shang, Y. C. 1976. Economic aspects of Gracilaria culture in Taiwan. Aquaculture 8:1–7.

Yang, S. S., Fang, C. Y. and H. H. Wang. 1981. Seasonal variation of agar production in Taiwan area. Proc. Int. Seaweed Symp., 10:737–742.

Zheng C. K., Wang, S. J. and S. J. Liu. 1987. Phycoculture, Shanghai House of Science and Technology Publication. pp. 225–254.

STUDY OF THE INTENSIVE CULTURE OF UNDARIA ON THE COAST OF BRITTANY*

R. KAAS & R. PEREZ

IFREMER Center de Nantes
Rue de l'Ile d'Yeu, Boite Postale 10492
44037 Nantes, France.

In 1971, the brown seaweed Undaria pinnatifida appeared in the Thau lake on the French Mediterranean coast. It was probably introduced with oysters imported from Japan and spread slowly from the lake to the open shore. So, it can now be found from Sete to Port-Vendres.

This seaweed being edible, it was established that there is in Europe and in North America a potential market for Undaria and a constant demand from Asia. So, trials have been made to develop its cultivation in France. However, it would be difficult to achieve good results in the Thau lake and along the Mediterranean coast because the temperature of the seawater and the light intensity increase too rapidly in early spring; consequently, these phenomena squeeze into too short a period the time during which Undaria is of good commercial interest. So the idea to try to cultivate it in less warm water led us to make some experiments on the Atlantic coast of Brittany. The goal was to get two crops a year.

The cultivation technique

The methods involves cultivation in a tank of large quantities of young plants fixed on a string rolled around a square plastic frame. String and frame constitute the collector for spores or gametophytes. When the plants become visible to the naked eye, the well-covered string is unrolled from the plastic frame, put out to the sea and wrapped round a long line rope, one meter beneath the surface, parallel to the prevailing waves. The methods includes three steps:

- the production of seeds,
- the pre-culture in tanks,
- the cultivation in the open sea.

*= Presented and discussed by Mr. Yves Henocque, IFREMER Regional Manager (Asia- Pacific) Economic Affairs and International Cooperation

Production of the seeds

Korean, Japanese and Chinese seaweed-farmers seed the collectors directly with spores released by ripe Undaria sp. between May and June. Then the frames are hung in a shaded tank of seawater for a period of four months before being transferred outdoors. The water must be changed each week and every two or three days. The collectors must be cleared from mussels, diatoms, Ectocarpus, Cyanophyta and other intruders by cleaning with a soft brush. The technique is very costly because it needs much time and many people.

Furthermore, it allows only one seeding period and consequently only one crop a year.

IFREMER applied another seeding process by using a vegetative gametophyte technique in flasks, known as the free-living technique. This method is able to provide large amounts of male and female gametophytes issued from only several selected spores.

As a matter of fact, there is a critical point at 21–22 °C under 40 umol m^{-2} s^{-1} in continuous daylight where the Undaria gametophytes lose their capacity for gametogenesis but continue to grow quickly until they are broken by the motion of the water; each part of them grows again and again if cut, and so on, and because of increasing density of gametophytes, the flask darkens more and more. New flasks can be seeded from the darkened one; they will undergo the same process if the critical conditions are maintained. The free-living method permits one to have gametophyte-seeds all through the year on condition that competitors, such as cyanophyta and diatoms, cannot develop in the flasks. For this purpose germanium dioxide at 2.5 ppm is used against diatoms and a specific antibiotic, kanamycin, at 50 ppm inhibits blue green algal growth.

When the time comes to seed the collectors, the flasks are first put in special conditions: by decreasing the temperature slowly to 17 °C and increasing the light intensity to 55 umol m^{-2} s^{-1}, it is possible to make them become fertile.

Then, the black gametophyte solution is spread on both sides of the collectors. To obtain a good hold of the gametophytes, it is necessary to use a well-dried fluffy string which quickly sucks up the beads, jams the gametophytes between the fibres of the string which quickly sucks up the beads, jams the gametophytes between the fibres of the string and holds them in spite of the water motion.

The collectors are hung under a bank of daylight fluorescent tubes in tanks containing 0.2 um filtered water, to avoid any kind of competition. We use tanks 3 m long, 1.25 m broad and 1 m high able to receive 60–80 string rolled frames at a time. The filtered water change occurs every three days. It needs three weeks until the young plants can be seen with the naked eye. Their size is then around 1 mm and it is possible to bring them to the sea.

Cultivation in the open sea

The outdoor experiments are carried out on the coast of the Ouessant Island in the North-East of Brittany with the help of the fishermen cooperative.

The well-covered strings are unrolled from the frame and rolled round parallel horizontal ropes, 100 m long, stretched at one meter depth under the surface. We seeded 50 ropes a hectare. The distance between two ropes was 2 m.

The trials show that it is better to transfer the young plants to the sea before they reach 2 mm, otherwise, many of them are uprooted due to a weak attachment of their holdfasts or to diseases which appear rapidly after a three-week indoor culture. We do not know why. Three hypothesis can be advanced:

- deficiency of an unknown nutrient needed at this size,
- bacterial attack, which could be attached to the weakness of the plant from lack of a given nutrient;
- lack of water motion.

We observe highly reduced losses after transfer to the open sea if, during the last week indoors, a strong water motion is induced in the pre-culture tank by an immersed pump; the motion certainly increases holdfast attachment. Furthermore, if the filtered seawater in the tank becomes running, or is changed each two days, the diseases do not appear. Research has been focused on these points to define the best transfer method.

In the sea, the plants grew rapidly, mainly when the temperature was between 9 and 12 °C, from December to April. They reached on average 5 cm 10 days after the transfer, 20 cm the 30th day, 90 cm the 60th day, 260 cm and more after the 4th month.

Two crops of 40 tons/hectare were harvested, the first at the beginning of February following a germling transfer in September, the second at the end of May following a transfer in February. We have tried starting a new outdoor culture in May but the plants stopped growing when they reached 20 cm long and developed rapidly a sporophyllum; it seems that this early maturation is induced by the long daylight. This last crop yielded less than the other ones: 20 tons/hectare.

Conclusion

Following our experiments of 1988 and 1989, French fishermen started to cultivate Undaria. The seeding by free-living gametophytes makes them free from the natural biological cycle of the seaweed. The production of young plants can occur as they want and need only three weeks instead of four months as in Asia.

Two crops a year would make them more competitive, in front of Asian farmers. The quality of the seaweed along the Brittany coast is of high commercial value.

In our experiments the output was only about 7 kg/m. But this low value was due to the fact that the quantity of Undaria growing outdoors was so high that the buoys were not powerful enough to hold all the ropes at the desirable level; some ropes plunged to the bottom and lost their plants, eaten by many animals.

It seems that the yield can be increased by (a) rolling two strings round each sea rope instead of one, (b) bringing the ropes closer than 2 m each from each other, and (c) by increasing the number and the size of buoys to maintain strongly the ropes at the optimal growing level.

ENVIRONMENTAL ASPECTS OF SEAWEED CULTURE

M. J. PHILLIPS

Institute of Aquaculture
University of Stirling
Stirling FK9 4LA
Scotland

The impact of aquaculture on the environment and effects of environment on aquaculture production have become important issues in recent years. There is evidence from many countries that environmental deterioration is a major threat to aquaculture production and product quality. There is also evidence that marine and freshwater aquaculture can cause environmental change, which in some cases may adversely affect the long-term viability of the aquaculture operation itself, or result in serious conflicts with other users of aquatic resources. These problems have led to a need to consider aquaculture as one component in the aquatic ecosystem and to plan aquaculture development in a way which makes efficient use of resources. There have been several recent reviews of impacts associated with finfish (Beveridge, 1984; NCC, 1989), mollusc (ICES, 1989; NCC, 1989) and crustacean (Phillips et.al, 1990) culture but there is little information on seaweed culture.

The main environmental impacts caused by aquaculture have been reviewed in several recent publications (NCC, 1989; ICES, 1989; NCC, 1990) and can be summarised as follows:

i. physical effects, including effects on water movement, the physical structure of terrestrial and aquatic habitats and aesthetic impacts;

ii. ecological effects, including changes in water quality, primary and secondary productivity and native fisheries.

These effects have arisen in many forms of aquaculture, although impacts vary considerably depending on the nature of the culture system and species cultured, plus the environment where the culture system is located. The main impacts and problems come from intensive aquaculture with high stocking densities and supplementary feeding, but problems have also arisen in extensive aquaculture systems.

Seaweed culture has expanded rapidly over the past few years, and in 1987 3,139,473 tons (wet weight) of seaweed were produced throughout the world, the bulk produced in Eastern Asia (FAO, 1989). This expansion has brought benefits in terms of income, employment and foreign exchange, but has also been accompanied by some conflicts with other users of the coastal zone and concerns over potential environmental impacts. The aim of this review is to consider some of the environmental implications associated with seaweed culture and ways in which issues may be resolved.

Physical aspects of seaweed culture

Seaweed culture is practiced using a very diverse range of culture methods and each of these methods will interact with the environment in different ways. The nature of this interaction and environmental impact will depend on the method of culture, the surface area (and three dimensional volume) of the farm, and the site where the farm is located. In general, several physical impacts can be recognized, which may have both positive and negative effects on the environment (Table 1).

The main impact of pond culture is the space used for ponds, which is unlikely to cause significant harm where ponds are located in unfertile and underutilised land. Gracilaria culture has been developed in abandoned shrimp ponds in the Philippines, Thailand and Indonesia, thus making use of otherwise wasted resources.

The main physical impact of sea-based systems probably stems from the large surface area required for viable seaweed culture in many areas but there may be others caused by site preparation, routine management and the culture system.

Site preparation of some species involves removal of rocks and other obstructions and potentially competitive grasses or predators (Juanich, 1988). Such operations could result in some damage to coastal ecosystems, and in some instances the loss of some species of conservation interest, such as seagrasses (Pullin, 1989). The routine management of seaweed farms in shallow waters, such as Gracilaria or Eucheuma farms, can result in additional damage through trampling and accidental damage.

The physical shading of an area by seaweed farms may also occur, resulting in changes in benthic communities and primary production in the water column (later section) although these effects have not been well studied.

There is also some potential for large scale farms, such as the large areas covered by Laminaria japonica culture in China, to influence coastal water movement. There is the possibility of enhanced sedimentation but also that seaweed farms can protect coastal areas from erosion. Large seaweed farms may also help to protect other more sensitive culture species and systems. For example, in China, Laminaria japonica culture zones are used to shelter areas where more fragile and sensitive culture species and systems, such as mussel or scallop culture are located.

Introduction of seaweed culture rafts, ropes, anchors and other structures can increase the surface area of substrate, which particularly in open waters may enhance production of other marine organisms, particularly in otherwise barren areas, much in the same way that artificial reefs have been shown to do (see below). Seaweed culture may also be used very effectively to rehabilitate degraded coastal areas and enhance production from otherwise unproductive and barren environments.

Aesthetic aspects and multiuser conflicts

The potential aesthetic impact of aquaculture has dominated arguments over aquaculture development in some countries and aquaculture planners are having to ensure that potential aesthetic changes are considered during the development of new aquaculture ventures in order to avoid conflicts with other users (Dixon et al., 1990). The recent conflict over the development of seaweed farming on Tubbataha Reef in the Philippines is probably one example where some of the user conflicts were derived from concern over potential aesthetic impacts.

The large area required for economically viable seaweed culture is in some countries resulting in significant conflicts with users concerned with visual impact and others such as fishermen and tourists concerned with access (Merrill, 1990). The potential 'spacial' implications for seaweed culture may become an important constraint to development in some areas in Asia and other parts of the world as competition for coastal and near-shore resources intensifies. These problems could perhaps be resolved by strategic planning or use of appropriate culture technologies. The use of submerged culture techniques or careful site selection could be used to avoid some visual impacts in sensitive locations. Development of offshore culture zones could also reduce conflicts, as well as making more efficient use of offshore resources.

Ecological aspects of seaweed culture

The positive and negative ecological aspects are summarised in Table 2.

The use of supplementary feed in intensive aquaculture systems results in a net increase in nutrient levels and primary productivity in waters receiving effluent (NCC, 1989). Seaweed culture is an extensive culture system which relies mostly on a natural nutrient supply. For example, studies in Republic of Korea and Japan have shown a good correlation between nutrient concentrations and Undaria production (Chung, 1986). The reliance on natural nutrient supply is such that there is potential for seaweed culture to deplete coastal waters of nutrients. Studies in China show reduced nutrient levels in Laminaria japonica culture areas (UNDP/FAO, 1989). The effects of nutrient depletion have not been well-studied, but nutrients diverted through the macroalgae, rather than phytoplankton food chains could affect patterns of nutrient recycling and secondary productivity. The removal of nutrients in high density culture areas also has implications for the long-term viability of seaweed farming itself.

There are examples from extensive finfish and mollusc aquaculture where overstocking of culture areas has resulted in a decline in natural productivity and eventual decrease in aquaculture production. Milkfish culture in Laguna de Bay is a classic example of overstocking in relation to the 'carrying capacity' of the environment (Beveridge, 1984) and there are other examples from Europe, Asia and North America where mollusc production has suffered badly following a few years of operation, as a result of overstocking (ICES, 1989). There are indications that it is also possible to over-intensify seaweed farming and that in some locations over-production is resulting in outbreaks of disease and production losses. Studies in China show that outbreaks of disease in seaweeds may be linked to nutrient decline (UNDP/FAO, 1989) and over-intensification in the Republic of Korea is blamed for the serious disease losses in Undaria and Porphyra culture (Gong, 1990). These problems, which may grow as the seaweed industry continues to develop, highlight the need to carefully consider the 'carrying capacity' of the local coastal environment which balances the ecological requirements of the cultured seaweeds with the capacity of the environment to provide these needs.

In some areas, problems of nutrient depletion are reduced by fertilization. For example, studies in China have shown that fertilization of Laminaria japonica culture areas may be necessary when nitrate levels fall below 20 ug/1 (UNDP/FAO, 1989). Fertilization is normally with inorganic fertilizers or occasionally with organic manure. This fertilization has a positive benefit on the growth of seaweed and has been shown to enhance the productivity of phytoplankton and invertebrates in the culture zones (UNDP/FAO, 1989). The wider environmental effects are unknown.

In intensive and semi-intensive aquaculture, various chemicals have been used for the prevention and control of disease, water treatment, removal of predators and prevention of fouling organisms. In some cases concern has arisen over the potential impacts of such chemicals on the environment and the health of farm workers and consumers. So far, there are only a few reports of chemicals used in seaweed culture to control disease, remove fouling organisms and predators and to assist processing. Formaldehyde has been used for controlling the growth of epiphytes on Gracilaria (Santelices and Doty, 1989) and slaked lime has been used to control other predators (North, 1987). It is important to ensure that practices continue to be conducive to production of a healthy project with minimal environmental impact.

The influence of seaweed culture on benthic communities has not been well studied. Shading or smothering by large scale seaweed farming could potentially reduce benthic productivity in shallow inshore areas. Increased sedimentation of organic matter from seaweeds and associated organisms could also increase benthic production in areas with low current velocity, although there may be some community changes. The area below seaweed culture areas can be used very positively for production of other aquatic animals. For example, farms in Republic of Korea, Japan and China find that the benthic area below seaweed farms can be used for culturing of invertebrates, such as abalone or sea cucumber, thus maximising the production and profit per unit area.

The seaweeds and farm structures (ropes, buoys, rafts, etc.) may also have a significant influence on coastal invertebrate and vertebrate populations. The introduction of seaweed and structures can considerably enhance the productivity of invertebrates and fish much the same way as artificial reefs, due to increased availability of shelter and food organisms. Studies in Japan have shown that Laminaria japonica farms act as shelters for commercially important fish fry and workers in China have shown increased numbers of fish, sea urchins, sea cucumbers and abalones in giant kelp culture areas (Ruying et al., 1986). The attractiveness of seaweed farms can also cause problems for seaweed farmers, by attracting invertebrates and finfish which may predate on the seaweed (North, 1987).

Impacts of environment on seaweed culture

The culture of seaweed is also significantly influenced by environmental factors in several countries in Asia. Turbidity, nutrient levels, phytoplankton blooms, temperature, salinity fluctuations are all significant factors in the successful development of culture areas. Many of the broad ecological requirements are well known (eg Trono, 1986). However, the deteriorating water quality in some coastal locations is also a threat to present and future seaweed culture, as a result of increased turbidity, pollution by heavy metals and organic pollutants. It is well known that seaweeds are efficient at absorbing heavy metals (Cajipe, 1990) and any benefits obtained from hypernutrification (nutrient enrichment) could easily be offset by a loss of product quality when enhanced nutrient loadings are also accompanied by high levels of heavy metals and other industrial, agricultural and domestic pollutants. It is therefore advisable to site seaweed farms away from areas with heavy pollutant loads. There appears to be little information on pollutant residues in seaweeds cultured in Asia but close attention by producers and researchers to the potential problems is warranted to avoid future problems.

Introduction of non-native species and other interactions between cultured and wild stocks

The world-wide expansion in aquaculture has resulted in a very significant increase in the number of species of aquatic animals and plants which are moved beyond their native ranges for the purposes of aquaculture (Welcomme, 1988). These translocations in many instances bring positive improvements in aquaculture production, but also carry the risk for potential adverse effect on aquaculture and wild species, either through introduction of new diseases or competition with native species. The concern is such that Codes of Practice are now being drawn up by the ICES and EIFAC to try and mitigate potentially harmful effects (Turner, 1988).

In common with other aquatic organisms, seaweeds have also been accidentally or deliberately transplanted beyond their native range, with positive and negative impacts. Laminaria japonica is native to Japan. It was accidentally introduced to the northern Yellow Sea in 1927, and further deliberate introductions established it in the marine flora of China, where it forms the basis of the largest seaweed industry in the world. Introduction of species into other parts of the world has been more controversial. For example, there is concern over impacts of recent introductions of Sargassum muticum and Undaria pinnatifada in Europe (probably introduced on molluscs from Japan). Sargassum muticum has spread throughout much of Western Europe in recent years, from Northern Spain to Sweden, and is now regarded as a major nuisance species in Western Europe causing significant problems to navigation in some areas (Rueness, 1989). Experiments in France with the culture of Macrocystis pyrifera were abandoned in the 1970s due to concern over potential adverse impacts (Rueness, 1989). The ecological implications of introductions are difficult to assess but the potential risks are such that careful assessment of potential impacts should precede the introduction of any new species (Turner, 1988).

The selective breeding of aquatic organisms has been an important factor in the success of aquaculture, but there is concern that the increasingly selective breeding may result in loss of native local species through competition or genetic changes, but these effects have not been studied.

There is no evidence that seaweed diseases have been transferred as a result of seaweed culture, unlike other forms of finfish, crustacean and mollusc culture where there are many documented examples of translocation of pathogens as a result of movements of cultured animals (Welcomme, 1988; NCC, 1989).

Polyculture with seaweeds and integrated seaweed culture

There is potential with some culture systems to integrate seaweed culture with other forms of aquaculture to make better use of marine resources and reduce the impacts of more intensive forms of aquaculture (Table 3).

The polyculture systems developed in Eastern Asia, with Laminaria - abalone, Laminaria - scallop and Laminaria - Undaria can be used to improve the productivity and profitability per unit area. There is also good evidence that polyculture of seaweeds with mollusc may also enhance the production of both Laminaria and mollusc in comparison with monoculture systems (UNDP/FAO, 1989).

There is also scope for improved integration of seaweed culture with other forms of aquaculture. Seaweed farming is generally an extensive farming method involving a net uptake of nutrients from coastal environment. In contrast, coastal ecosystems through addition of nutrients derived from uneaten feed, faeces and dissolved excretory materials (NCC, 1989). There is therefore some scope for integrating intensive culture of finfish with seaweed culture to reduce hypernutrification resulting from cage culture and to improve seaweed production. Experiments in Japan have shown that cage culture of yellowtail (Seriola quinqueradiata) and red sea bream (Pagrus major) can be successfully integrated with Laminaria culture. Environmental studies have shown that alternate rows of seaweed and finfish cages help to improve dissolved oxygen concentrations during daytime hours and reduce levels of potentially harmful ammonia. Recent studies by Levin (1990) have also demonstrated that Porphyra palmata reduced ammonia concentration by 60% and phosphorous by 32% in effluent from land-based salmon mariculture systems. Neori (1990) has also shown that Ulva lactuca and Gracilaria conferta can be used to remove ammonia from effluent from intensive Sparus aurata ponds. In Thailand, polyculture of Gracilaria on grouper cages can yield 16–20 kg (fresh weight) of seaweed per month in a 5 x 6 x 2 m cage, providing an extra source of income for the farmer, as well as possibly improving conditions for the caged fish.

The uptake of nutrients by seaweeds offers scope for improving the quality of effluent discharged from land-based aquaculture operations. In Thailand, experiments are being carried out using Gracilaria to remove nutrients from effluent water in attempts to reduce the impact of effluent on receiving waters. In Thailand and Taiwan, experiments are underway to assess the potential for using Gracilaria to improve the quality of water entering shrimp ponds. Unpublished studies in Taiwan indicate that Gracilaria can be used to remove ammonia, heavy metals and trace organics before water enters the shrimp ponds.

These forms of integrated aquaculture offer good scope for the development of techniques which make efficient use of the coastal environment and maximising the production per unit area and in some cases for reducing some of the environmental impacts associated with intensive aquaculture.

Discussion

This review highlights some of the positive and negative environmental aspects of seaweed culture. The most important impact probably derives from the surface area needed to develop viable operations in some locations. This space requirement has resulted in conflicts with other coastal zone users, and will continue to do so in the future as pressures on the coastal zone intensify. These conflicts could be avoided by a balanced approach to development on the basis of sound scientific data on impacts and strategic planning, which optimises the socio-economic benefits of alternative development strategies. The adoption of zoning policies for seaweed and other aquaculture development could be advocated as one approach to a more balanced use of coastal resources for aquaculture.

There are also indications from some countries that some culture areas are suffering disease outbreaks and production decline which may be linked to overstocking in relation to the 'carrying capacity' of the coastal environment. Site requirements need to be modified to better understand the carrying capacity of culture zones to avoid longer-term environmental changes which may be detrimental to seaweed culture itself. The wider environmental impacts associated with seaweed culture should also be examined to ensure that resource use is based on a sound scientific basis.

There also exists potential for integration of seaweed culture with other forms of aquaculture to increase the productivity and socio-economic benefits per unit coastal area and to reduce impacts associated impacts associated with more intensive finfish and crustacean culture. The further development of these techniques on the basis of sound ecological and economic data is also recommended as a means of making efficient use of coastal resources for sustainable aquaculture development.

References

Beveridge, MCM. 1984. Environmental impact of cage and pen culture. FAO Fisheries technical paper.

Cajipe, G.J.B. 1990. Utilization of seaweed resources. In: Culture and use of algae in Southeast Asia. pp 77–79. Proceedings of the symposium on culture and utilization of algae in Southeast Asia, SEAFDEC AQD, Iloilo, Philippines.

Chung S.H. 1986. Comparative studies on the relationship between the laver production and environmental characteristics of laver farming area in the Republic of Korea and Japan. Bulletin of Fisheries Research and Development Agency, 37, 157–178.

Dixon, F. Cox, R. and Bourne, N. 1990. Shellfish and marine plant aquaculture in British Columbia - conflicts and solutions. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

FAO. 1989. Aquaculture production, 1983–87. FAO Fisheries Circular No. 815, Revision 1.

Fridley, R.B. and Scholz, P.M. 1989. Opportunities and constraints to development of marine aquaculture in the United States. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

Gong, Y.G. 1990. Status of production and utilization of seaweeds in the Republic of Korea. Paper presented at the 1st Asia-Pacific Workshop on Culture and Utilization of Seaweeds, 27–31 August 1990, Cebu City, Philippines.

ICES. 1989. Environmental impact of mariculture. International Council for the Exploration of the Sea, Mariculture Committee.

Juanich G.L. 1988. Manual on seaweed farming. 1. Eucheuma spp. ASEAN/SF/88 Manual No. 2, April 1988. ASEAN/UNDP/FAO Regional Small-scale Coastal Fisheries Development Project, Manila, Phil.

Levin, J. 1990. Salmon-macroalgae polyculture. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

Merril, J.E. 1990. The introduction of Porphyra (Nori) mariculture to Western North America. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

NCC. 1989. Fish farming and the safeguard of the Scottish marine environment. Nature Conservancy Council of the United Kingdom, Edinburgh, U.K.

Neshul, M., Amsler, C.D., Read, D.C. and Lewis, R.J. 1988. Dispersal of marine plants for aquacultural purposes. J. Shellfish Res, 7, (3), 555.

Neori, A. 1990. Seaweed biofilters in intensive mariculture. Paper presented at World Aquaculture '90. June 10–14, 1990, Halifax, N.S. Canada.

North, W.J. 1987. Oceanic farming of Macrocystis, the problems and non-problems. Seaweed Cultivation for Renewable Resources (ed. K.T. Bird and P.H. Benson, pp 39–68. Elsevier, Amsterdam.

Phillips, M.J. 1990. Lessons to be learned from world aquaculture's largest growth sector - brackishwater shrimp culture. ICLARM Conference on Third World Aquaculture and the Environment. Bellagio, Italy, 17–22 September 1990.

Pullin, R. 1989. Third World Aquaculture and the Environment. NAGA, ICLARM Newsletter.

Rueness, J. 1989. Sargassum muticum and other introduced Japanese macroalgae: biological pollution of European coasts. Marine pollution bulletin, 20, (4), 173–176.

Suo, R. Liu, G., Shi, Z., Wang, F., Zhang, S. and Liu, T. 1986. Cultural test with submerged floating rope on giant kelp in South Huangcheng Island. Marine Fisheries Research, 7, 1–7.

Santelices, B. and Doty, M.S. 1989. A review of Gracilaria farming. Aquaculture 78, 95–133.

Trono G.C. 1986. Seaweed culture in the Asia-Pacific region. RAPA Publication, 1987/8. Regional Office for Asia and the Pacific, UNFAO.

Turner, G.E. 1988. Codes of practice and manual of procedures for consideration of introductions and transfers of marine and freshwater organisms. EIFAC/CECPI Occasional Paper, No. 23, 44 p.

UNDP/FAO. 1989. Culture of Kelp (Laminaria japonica) in China. Prepared for the Laminaria polyculture with mollusc training course conducted by the Yellow Sea Fisheries Research Institute in Qingdao, China and organized by the Regional Seafarming Development and Demonstration Project (RAS/86/024).

Welcome, R.L. 1989. International introductions of inland aquatic species. FAO Fisheries Technical Paper, (294): 318 p.

Table 1. Potential physical issues associated with seaweed culture indicating their potential positive and negative effects.

OPERATION AND ISSUES	POSITIVE EFFECTS	NEGATIVE EFFECTS
Cleaning and preparation of culture areas * > ** **	Improved production and management	Potential loss of native species and habitat diversity
Routine management (weeding, harvesting) * > ** **	As above	As above
Shading by growing seaweed * > ** **	Reduced competition	Reduced water column and benthic production
Attenuation of waves and water currents * > *** **	Shelter for sensitive species	Increased sedimentation
Aesthetic issues * > *** **	Enhanced coastal productivity in degraded ecosystems	User conflicts Loss of resource value
Space * > *** **	Enhanced productivity of barren or degraded ecosystems	User conflicts (e.g. with fishermen)
Substrate area and volume * > *** **	Enhanced productivity of barren or degraded ecosystems	Ecosystem changes

*+ minimal effects
** + potential for significant effects

Table 2. Ecological issues and seaweed culture, indicating their potential positive and negative benefits.

OPERATION AND ISSUES	POSITIVE EFFECTS	NEGATIVE EFFECTS
Water quality * > ** **	Enhanced oxygen, removal of nutrients, seaweed production	Reduced coastal phytoplankton Nutrient cycling 'Diseases'
Fertilization and chemical treatments * > ** **	Seaweed production Enhanced polyculture production	Product quality Water quality changes
Benthos * > ** **	Enhanced polyculture polyculture (e.g. with mollusc)	Changes in benthic species and production
Water column productivity * > *** **	Enhanced production of invertebrates and finfish Shelter of fish fry Polyculture	Predators Changes in community structure

*+ minimal effects
** + potential for significant effects

Table 3. Polyculture and integrated culture systems involving seaweed

CULTURE SYSTEM	BENEFITS
Laminaria - abalone	Efficient use of 3-D water column
Laminaria - scallop	Increased production per unit area
Laminaria - Undaria	Increased production of each species
Laminaria - finfish cage culture	Enhanced productivity of seaweed and finfish culture operations. Increased income per unit area
Gracilaria - grouper cage culture	Increased dissolved oxygen Reduced ammonia and other nutrients Reduced environmental impact
Gracilaria - shrimp pond culture	Removal of toxic metabolites from ponds and effluent water Improved quality of inflow water after removal of heavy metals, organic pollutants and nutrients.

THE MASS CULTURE OF DUNALIELLA SALINA

MICHAEL A. BOROWITZKA

Algal Biotechnology Laboratory
School of Biological and Environmental Sciences
Murdoch University
Murdoch, W.A. 6150
AUSTRALIA

Introduction

The green unicellular flagellate Dunaliella salina Teodoresco is the richest natural source of the carotenoid β-carotene (Borowitzka, MA and Borowitzka, 1988 a). The halophilic species of Dunaliella also accumulate very high concentrations of glycerol (Borowitzka, LJ and Brown, 1974; Borowitzka, LJ, 1981 b). Dunaliella salina was first proposed as a commercial source of B-carotene by Massyuk (Massyuk, 1966) and later as a source of glycerol (Ben-Amotz et al., 1982 b). β-carotene from Dunaliella is now being produced on a commercial scale in Australia, the USA and Israel, and pilot-scale projects are under way in China, Chile, Australia, the USA, Spain and Kuwait. More recently D. viridis has also been proposed as a source of oxygenated carotenoid (Moulton and Burford, 1990).

Taxonomy, life-history and morphology

Dunaliella is a unicellular, bi-flagellate, naked green alga (Chlorophyta, Chlorophyceae). The genus was first described by Teodoresco (Teodoresco, 1905) with the type of species being Dunaliella salina, and at present a total of 29 species, as well as a number of varieties and forms, are recognized (Massyuk, 1973).

Dunaliella is morphologically similar to Chlamydomonas, with the main difference being the absence of a cell wall in Dunaliella. Dunaliella has two flagella of equal length and a single, cup-shaped chloroplast, which in the marine and halophilic species has a central pyrenoid (Borowitzka, MA & Borowitzka, 1988a). In D. salina and D. parva the chloroplast accumulates large quantities of B-carotene so that the cells appear orange-red rather than green. The carotenoid are in the form of droplets (plastoglobuli) located at the chloroplast periphery and consist of a mixture of the cis- and transisomers of β-carotene (Ben-Amotz et al., 1988). A typical composition, expressed as percentages of total β-carotene is 15-cis-β-carotene, 10%; 9-cis-β-carotene, 41%; all-trans-β-carotene, 42%; other isomers, 6% (Ben-Amotz et al., 1982a; Borowitzka, LJ & Borowitzka, 1989a). In the alga this β-carotene seems to act as photo-protective 'sun-screen' to protect the chlorophyll and the cell DNA from the high irradiance which characterizes the normal habitat of D. salina (Ben-Amotz, 1980; Ben-Amotz et al., 1989). Borowitzka and Borowitzka (1988a) have also proposed that the β-carotene also acts as a 'carbon sink' to store the excess carbon produced during photosynthesis under conditions where growth is limited but photosynthetic carbon fixation must continue.

Cell shape in this genus is very variable, being oval, spherical, cylindrical, ellipsoidal, egg-, pear- or spindle-shaped with radial, bilateral or dorsoventral symmetry or being asymmetrical. Cells in any given species may change shape with changing conditions, often becoming spherical under unfavorable conditions. Cell size also varies with growth conditions and light intensity (Massyuk, 1973).

The cells divide by lengthwise division in the motile state. Under certain conditions they may also develop into a palmella stage and become embedded in a thick layer of mucilage, or they may form aplanospores with a thick, rough wall. Sexual reproduction is rarely observed in cultures, but more often in the field. It is by isogamy, with conjugation proceeding in a manner similar to that observed in Chlamydomonas. The zygote is green or red and is surrounded by a very thick, smooth wall of sporopollenin. After a resting stage the zygote nucleus divides meiotically, forming up to 32 cells which are liberated through a rupture in the mother cell wall (Borowitzka, MA et al., 1982).

Ecology

The genus Dunaliella has marine and halophilic representatives. Freshwater species have also been described although Melkonian and Preisig (1984) have proposed that these should be assigned to a different genus. Dunaliella also has a very wide pH tolerance ranging from pH 1 (D. acidophila; Gimmler et al., 1989) to pH 11 (D. salina). In fact, D. salina is one of the most environmentally tolerant eukaryotic organisms known and can cope with a salinity range from seawater (= 3% NaCl) to NaCl saturation (= 31% NaCl), and a temperature range from <0 °C to >38 °C (Ginzburg, 1987; Borowitzka, MA & Borowitzka, 1988a).

Dunaliella species are commonly observed in salt lakes in all parts of the world from tropical to temperate to polar regions where they often impart an orange-red colour to the water. Marine Dunaliella species can generally be isolated from seawater, although they are not very abundant in nature. More details of the ecology of this genus can be found in Borowitzka and Borowitzka (1988a).

Mass culture

The main interest in this genus in recent years has been in the halophilic species Dunaliella salina since it is the source of β-carotene (in some papers this species is also referred to as D. bardawil, however, this is an incorrect name for D. salina, furthermore, several other cultures referred to in the literature have been incorrectly identified and Table 1 gives the correct name for these).

The large-scale culture of D. salina requires a good understanding of the physiology and ecology of the alga. These aspects will be discussed here first.

Physiology

The physiology of Dunaliella, especially D. salina is reviewed in detail by Ginzburg (1987) and Borowitzka and Borowitzka (1988a) and the present account will only consider the most important facets for mass culture. The most commonly used medium for culture of Dunaliella is Modified Johnsons Medium (Table 2), however, these algae can also be grown in a wide range of other media including Guillard's f/2 medium (Guillard & Ryther, 1962), modified ASP medium (McLachlan & Yentsch, 1959) and enriched seawater (Rao & Chauhan, 1984).

Nutrient requirements

Carbon source. All Dunaliella spp. so far studied are strict photoautotrophs. Dunaliella appears to be able to take up CO_2 and HCO_3 for photosynthesis, and Aizawa and Miyachi (1984) and Brown et al., (1987) have demonstrated the presence of an extracellular carbonic anhydrase in D. tertiolecta. The supply of inorganic carbon is particularly important to the culture of D. salina since, at the very high salinities at which this alga grows, the solubility of inorganic C is low; i.e. at 25% NaCl the solubility of inorganic carbon is <50% of that at seawater salinity (3% NaCl). Furthermore, at the high temperature and pH usually found in the natural brines in which D. salina grows, the bulk of the inorganic carbon (>99%) is in the form of CO_3^{2-} and is thus unavailable for uptake by the algal. The presence of an extracellular carbonic anhydrase which catalyses the conversion of HCO_3^- to CO_2 means that the alga can utilize HCO_3^- under these conditions.

Table 1. Probable taxonomic affiliation of some strains of Dunaliella salina and other misnamed species reported in the literature.

Strain	Evidence	Probable Taxon
D. salina UTEX 200 = CCAP19/3	Does not turn red at salinities up to 25% (Loeblich, 1982)	D. viridis
D. salina 'Strain No. 6' isolated by Massyuk at Sak salt works, Ukrainian USSR	Contains only 14.9 ug carotenoid per 10^6 cells at 29% NaCl (Mironyuk & Einor, 1968)	D. parva
D. salina ex W.H. Thomas	Contains only 3% β-carotene at 18% NaCl (3 M) (Ben-Amotz & Avron, 1982)	D. parva
D. salina Mil'ko strain (from Azov salt works by Aleshina)	Does not turn red	D. viridis
D. bardawil	Contains > 6% β-carotene (Ben-Amotz & Avron, 1983)	D. salina

Table 2. Modified Johnsons Medium (J/I) (Borowitzka, M.A., 1988).

To 980 ml of distilled water add:	
NaCl	as needed to obtain desired salinity
$MgCl_2 \cdot 6H_2O$	1.5 g
$MgSO_4 \cdot 7H_2O$	0.5 g
KCl	0.2 g
$CaCl_2 \cdot 2H_2O$	0.2 g
KNO_3	1.0 g
$NaHCO_3$	0.043 g
KH_2PO_4	0.035 g
Fe-solution	10 ml
Trace-element solution	10 ml
Fe solution (for 1 litre)	
Na_2EDTA	189 mg
$FeCl_3 \cdot 6H_2O$	244 mg
Trace-element solution (for 1 litre)	
H_3BO_3	61.0 mg
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	38.0 mg
$CuSO_4 \cdot 5H_2O$	6.0 mg
$CoCl_2 \cdot 6H_2O$	5.1 mg
$ZnCl_2$	4.1 mg
$MnCl_2 \cdot 4H_2O$	4.1 mg
Adjust pH to 7.5 with HCl	

Nitrogen source. The best source of nitrogen for Dunaliella is nitrate (Mil'ko, 1962; Grant, 1968; Borowitzka, MA & Borowitzka, 1988b). Ammonium salts such as ammonium acetate, ammonium nitrate and ammonium chloride are generally less effective N sources and at high concentrations and high temperatures can be lethal (Mil'ko, 1962). For example, experiments in our laboratory have shown that ammonium nitrate inhibits the formation of β-carotene, and in actively growing cultures uptake of the ammonium leads to an acidification of the medium which eventually results in the death of the algae (Borowitzka, MA & Borowitzka, 1988b). Urea can be used as a nitrogen source, especially in well buffered media. However, in large-scale outdoor cultures urea can lead to mass mortality of the culture due to the high concentrations of ammonium being released upon metabolism of the urea (Massyuk, 1966).

Phosphorous. Phosphate is the best source of P and the optimal concentration is about 0.02 to 0.025 $g.1^{-1}$ K_2HPO_4 (McLachlan, 1960; Mil'ko, 1962). High concentrations may actually inhibit growth.

Magnesium and calcium. Both of these cations are required for growth and Dunaliella can tolerate a wide Mg^{2+}:Ca^{2+} ratio ranging from 0.8 to 20.0. For D. tertiolecta a Mg^{2+}:Ca^{2+} ratio of 4 has been reported as optimal (McLachlan, 1960).

Sodium. All marine and halophilic species of Dunaliella require sodium.

Chloride and sulphate. The optimum Cl^-:SO_4^{2-} ratio for growth in D. salina is 3.2, whereas the optimum ratio for β-carotene formation is 8.6 (Massyuk, 1965). There also appear to be some interaction between the anions and the cations and their effect on the alga, however, this is as yet little understood.

Iron. Low concentrations of iron in a form that can be assimilated are essential for the growth of Dunaliella, and in some hypersaline brines Fe may be limiting to the growth of Dunaliella. The optimum concentration for iron in D. salina and D. viridis lies between 1.25 to 3.75 $mg.1^{-1}$ (Mil'ko, 1962) and should be supplied in a chelated form such as iron citrate or Fe-EDTA (Borowitzka, MA & Borowitzka, 1988b; Table 2). High concentrations of Fe inhibit growth.

Trace elements and vitamins. Various trace elements such as Zn, Co, Cu, Mo and Mn are usually added to Dunaliella media, however little is known of the actual requirements of the alga. Dunaliella does not require any exogenous vitamins for growth.

pH. The optimum pH for growth for the marine D. tertiolecta is pH 6, whereas for the halophilic D. salina and D. viridis it is about pH 9 (Loeblich, 1982).

Temperature. The optimum growth temperature for D. salina is in the range of 20 to 40°C (Borowitzka, LJ, 1981a) depending on the strain. Dunaliella salina can tolerate extremely low temperatures to below freezing (Siegel et al., 1984), but temperatures greater than 40°C are usually lethal. There is also a strong interaction between the growth rate, temperature and salinity (Gimmler et al., 1978; Borowitzka, MA & Borowitzka, 1988a) and between light intensity and temperature tolerance (Federov et al., 1968).

The physiology of carotenogenesis

Dunaliella salina is characterized by its ability to accumulate very high concentrations of β-carotene. Concentrations of up to 14% of dry weight have been reported (Aasen et al., 1969; Borowitzka, LJ et al., 1984). The halophilic species D. parva also accumulates high concentrations of β-carotene (<4% of dry weight), whereas none of the other species accumulate such large amounts (Massyuk, 1973). Recently, what appears to be a new species of Dunaliella has been isolated in Chile which accumulates not only high concentrations of β-carotene, but also a-carotene. High levels of β-carotene accumulation require high salinity, high temperature and high light (Mironyuk & Einor, 1968; Semenenko & Abdullayev, 1980; Ben-Amotz & Avron, 1983; Borowitzka, LJ et al., 1984; Ramazanov et al., 1988). Nutrient limitation, especially N limitation, also enhances carotenoid formation (Mil'ko, 1963; Ben-Amotz & AVron, 1983; Ben-Amotz, 1987; Borowitzka, MA & Borowitzka, 1988b). In general, carotenogenesis is greatest under sub-optimal growth conditions when the specific growth rate is low (Ben-Amotz et al., 1982a; Borowitzka, LJ et al., 1984). Table 3 summarizes the data on the effects of various environmental factors on growth and carotenogenesis.

Table 3. Summary of the influence of various environmental factors on biomass production and β-carotene content of cultures of D. salina. (+ = stimulating effect; - = inhibitory effect; 0 = no effect) (Based on Mil'ko, 1963; Borowitzka, LJ & Borowitzka, 1989a).

Factor	Biomass	β-carotene
Salinity increase	--	++++
Salinity decrease	+	(-)[a]
N deficiency	--	+++
P deficiency	--	+
Increase in inorganic carbon	+++	0
Increase in light	+	++++
Decrease in light	-	---
Temperature increase	+	++
Temperature decrease	-	-
Increase in O_2	-	-

a= Rate of decrease is very slow.

Light is essential for carotenogenesis (Loeblich, 1982; Ben-Amotz, 1987), but the maximum level of β-carotene in the cell is dependent on the salinity (Borowitzka, MA et al., 1990). Carotenoid formation is rapid. For example, when the salinity of a culture of D. salina is increased from 15 to 25% NaCl the total carotenoid increases linearly from < 10 to 260 mg (g cell protein)$^{-1}$ over a period of 4 to 5 days. The proportions of β-carotene increases from 50% to 90% during this period whereas there was no measurable increase in the other carotenoid, α-carotene, lutein and zeaxanthin (Borowitzka, MA et al., 1990).

Fortunately, from the mass culture point of view, the cell content of Bcarotene does not decrease at the same rapid rate when the salinity of the medium is reduced as occurs in outdoor cultures when it rains. When carotenoid-rich cells are transferred from a high salinity (25% NaCl) medium to a low salinity (15% NaCl) medium, there is only a gradual decline in cell carotenoid content over a period of several weeks (Borowitzka, LJ et al., 1984). Most of this decline is not due to β-carotene breakdown, but rather due to reapportionment of the β-carotene as the cells divide.

Commercial production of β-carotene from Dunaliella salina

As mentioned above, carotenogensis is greatest when growth is least. This represents the fundamental dilemma to the commercial producer wishing to produce β-carotene with Dunaliella salina. For commercial-scale production of B-carotene, or glycerol, one requires:

1. optimization of biomass production and product yield;
2. development of a reliable growth system which can cope with the vagaries of weather as well as potential predators and competitors;
3. a suitable, low-cost harvesting method;
4. appropriated downstream processing methods.

For large-scale outdoor algal cultures productivities of 30–40 g dry weight m^{-2}. day^{-1} seem to represent the present achievable limit over sustained periods. Over shorter periods, and in smaller culture systems productivities as high as 60 g dry weight.m^{-2}.day^{-1} have been recorded for Dunaliella (Ben-Amotz, 1980). However, many of the commercial production systems do not regularly achieve productivities of even 30 g dry weight.m^{-2}.day^{-1}. In fact, productivities are often substantially less. Also, it is generally observed, that the larger the individual ponds used to grow the algae, the smaller the productivity of the system seems to be.

In D. salina the optimum salinity for growth lies between 18 and 22% NaCl whereas the optimum salinity for carotenoid production is >27% NaCl (Borowitzka, LJ et al., 1984). By combining these data we find that the optimum yield of β-carotene per unit volume and time occurs at about 24% NaCl (Fig. 1).

Two strategies are open to the Dunaliella producer to maximize the production of β-carotene. One of these strategies is a two-stage growth process in which the algae are first grown at a low salinity (= 15% NaCl) in nutrient-rich medium to maximize biomass production, and then transferred to a high salinity, low nutrient medium in order to induce β-carotene production (Massyuk, 1966; Borowitzka, LJ et al., 1984). A similar, two-stage production process was proposed by Chen and Chi (1981) for glycerol production from Dunaliella. Such a process however, has several disadvantages. These are:

1. At low salinities protozoa such as the ciliate Fabrea salina and the amoeba Heteramoeba sp. can invade the culture and very rapidly decimate the algal production (Post et al., 1983; Borowitzka, LJ et al., 1985);
2. Lower salinities generally favour the growth of the non-carotenogenic Dunaliella species, D. viridis, D. minuta and D. parva (Borowitzka, LJ et al., 1985; Moulton et al., 1987). These species can overgrow the D. salina under these conditions and thus drastically reduce the B-carotene productivity of the pond.
3. A two-stage process is more labour intensive and also requires a greater pond area due to the slower throughput time. This results in greater capital and running costs and thus may make the process uneconomic (Borowitzka, LJ et al., 1984).

An alternative approach is to grow the algae in either batch or continuous culture at an intermediate salinity optimised for the best overall yield of β-carotene over time (Borowitzka, LJ et al., 1985). At the higher salinities used in this process the growth of predatory protozoa such as Fabrea salina, and the growth of the non-carotenogenic Dunaliella species are reduced and generally present no problem. Although growth rates are lower, the operating costs are also reduced and more importantly, the culture is not prone to sudden collapse.

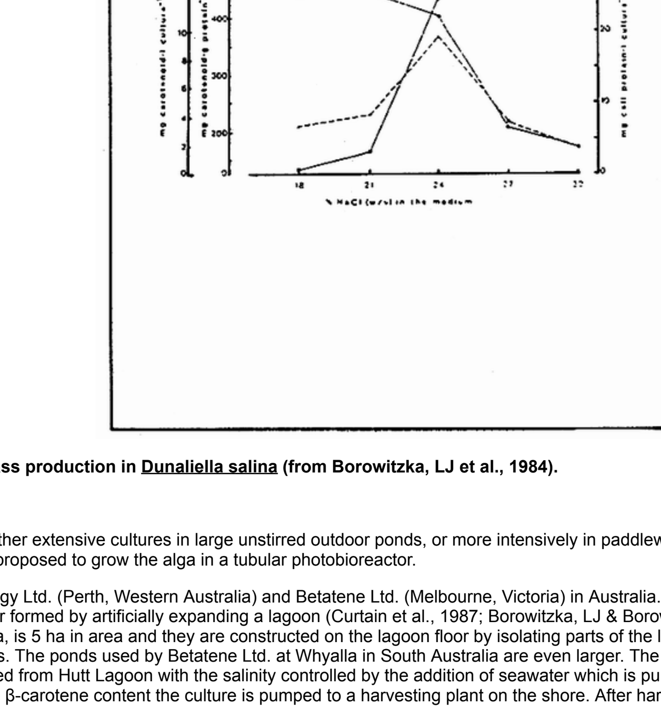


Figure 1. Effect of salinity on β-carotene content and biomass production in Dunaliella salina (from Borowitzka, LJ et al., 1984).

Culture systems

Commercial production of D. salina is presently carried out in either extensive cultures in large unstirred outdoor ponds, or more intensively in paddlewheel stirred raceway ponds. Photobioreactors Plc of the UK are also in the process of constructing a production plant in Spain where they proposed to grow the alga in a tubular photobioreactor.

The two largest producers in the world are Western Biotechnology Ltd. (Perth, Western Australia) and Betatene Ltd. (Melbourne, Victoria) in Australia. They grow the algae in very large and shallow (approx. 20 cm deep) ponds constructed either on the bed of a hypersaline coastal lagoon, or formed by artificially expanding a lagoon (Curtain et al., 1987; Borowitzka, LJ & Borowitzka, 1989a). For example, each of the production ponds used by Western Biotechnology Ltd. at Hutt Lagoon on the west coast of Australia, is 5 ha in area and they are constructed on the lagoon floor by isolating parts of the lagoon with earthen berms (Fig. 1). The production plant has a total pond area of 50 ha and there are also smaller ponds for research purposes. The ponds used by Betatene Ltd. at Whyalla in South Australia are even larger. The process used is summarized in Fig. 2. The algae are cultivated at high salinities in a medium made up of NaCl-saturated brines obtained from Hutt Lagoon with the salinity controlled by the addition of seawater which is pumped from a bore located on the seaward side of the lagoon. Nutrients are added as required. When the pond has reached the appropriate β-carotene content the culture is pumped to a harvesting plant on the shore. After harvesting the remaining medium is returned to the growth pond and the salinity and nutrient content is adjusted as appropriate. The rate of harvesting and the growth period varies with changing climatic conditions throughout the year.

The ponds are unlined and there are no mixing devices; the only mixing is by wind and thermal action. Although this form of extensive cultivation results in lower cell densities compared to a well mixed system, it is economically more attractive as long as an effective and cheap harvesting process can be used to extract the algae from the extremely high volumes of brines.

Paddlewheel-driven raceway ponds are used in Israel and the USA for the cultivation of Dunaliella. The biomass achieved in these ponds is generally an order of magnitude greater than in the unstirred ponds, however, construction and operating costs are greater. Details of paddlewheel raceway ponds and their construction and operation can be found in Oswald (1988) and Dodd (1986).

Each of the above culture systems has advantages and disadvantages, and the choice of system used at a particular site will depend on a number of factors. For example, if land costs and site preparation costs are high, then paddlewheel ponds are more economic. Similarly, since Dunaliella requires high concentrations of NaCl in the medium the source of the brine can have a major effect on the economics of the process. If high salinity brines are freely available, as in the case at Hutt Lagoon, then the extensive culture method is suitable. If, on the other hand, the brines have to be made up from salt, then the cost of this NaCl, even at US$ 13–16 ton^{-1} is significant. Finally, if climatic conditions mean that the annual growth period is short, then an intensive cultivation system is favoured. Sites such as Hutt Lagoon favour extensive cultivation because of: (1) low cost land and site preparation costs; (2) free source of brines; (3) a long - at least 9 months per year - growth season.

Closed culture systems are another alternative, however, at this time they still seem to be too expensive (Chaumont et al., 1988; Borowitzka, LJ & Borowitzka, 1989b). The advantages of closed systems such as the tubular photobioreactors are that contamination by other species of Dunaliella and protozoa can be virtually eliminated. The growth conditions can also be optimised and closely controlled, resulting in higher cell densities and better carotenoid yields per unit volume compared to open-air cultures. This also reduces harvesting costs. On the other hand, closed systems require pumping of the culture for circulation, and Dunaliella species are very sensitive to shear damage. As well as this, there is also the high capital cost of these systems and a higher operating cost. Large-scale closed algal culture systems are still in the early stages of development, and it is likely that in the future better and more economic designs will be developed, however, until then open-air culture will remain the preferred option for large-scale commercial algal culture.

Choice of site

Based on the observations above, a Dunaliella salina culture facility should be based at a site where:

1. there is ample flat land available;
2. there are cheap sources of high salinity brines, and also of lower salinity water (i.e. seawater) for salinity control and to provide the water for making up evaporative losses. The requirement for evaporative make-up water should not be underestimated. For example, a 5 ha pond at 20 cm depth contains 2 × 10^6 litres of water. At an evaporation rate of 1 cm per day, 100,000 litres of make-up water are required a day;
3. there are few cloudy days in the year and the mean daily temperature is >30°C for most of the year;
4. rainfall is as low as possible, and falls only during a small part of the year;
5. The site is as far away as possible from any source of pollution which might affect algal growth or contaminate the algal product which will be used as a high quality food additive. This means that the plant should not be near agricultural activities where pesticides or herbicides are used, nor should it be near industrial activities which may emit heavy metals.

Harvesting

Harvesting and extraction represent the major cost areas in most algal processes. Harvesting D. salina is more difficult and costly compared to most other commercially produced algae, and therefore the methods used by the various commercial producers are closely guarded.

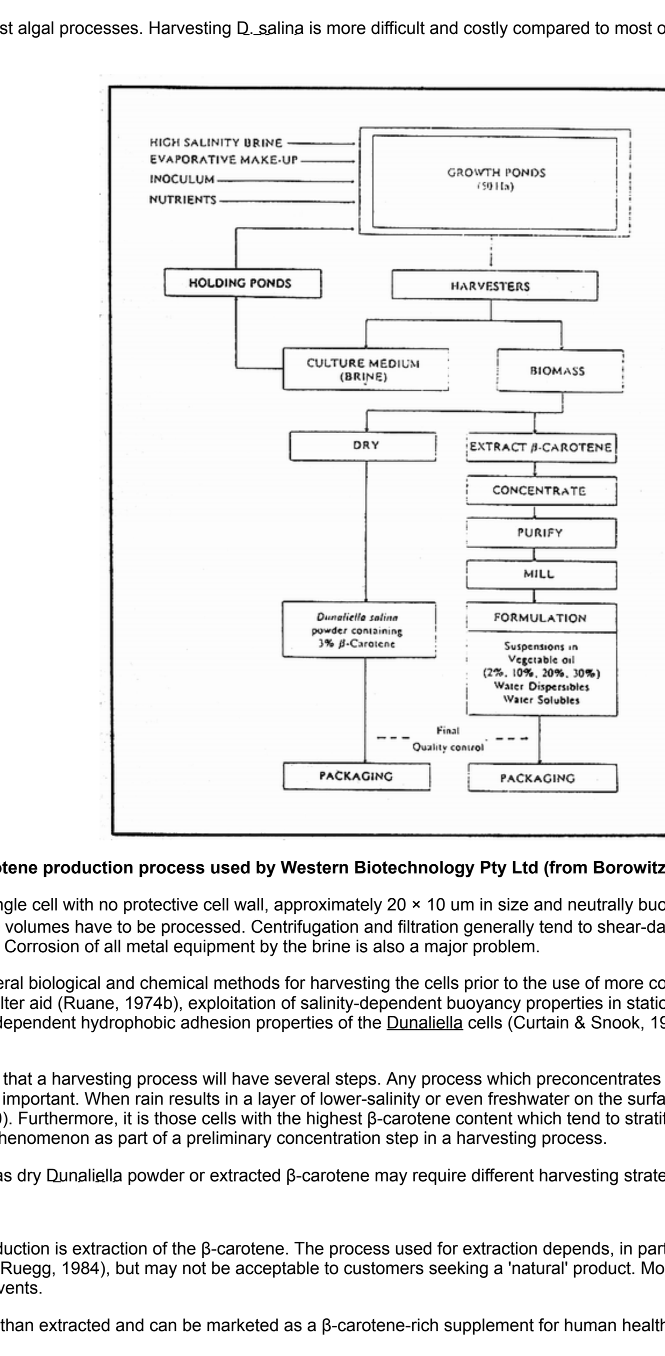


Figure 2. Schematic flow diagramme of the D. salina β-carotene production process used by Western Biotechnology Pty Ltd (from Borowitzka, L.J. & Borowitzka, 1989a).

The difficulty in harvesting D. salina is because this alga is a single cell with no protective cell wall, approximately 20 × 10 um in size and neutrally buoyant in a high specific gravity, high viscosity brine. Cell densities in large-scale cultures tend to be about 1 g. 1^{-1} and therefore very large volumes have to be processed. Centrifugation and filtration generally tend to shear-damage the cells, leading to loss of the β-carotene by oxidation. The cells also distort and pass through filters with pore sizes less than 10 um. Corrosion of all metal equipment by the brine is also a major problem.

These problems have led to development and patenting of several biological and chemical methods for harvesting the cells prior to the use of more conventional harvesting methods. Patents issued for Dunaliella harvesting include high pressure filtration using diatomaceous earth as a filter aid (Ruane, 1974b), exploitation of salinity-dependent buoyancy properties in stationary and moving gradients (Block et al., 1982), exploitation of the phototactic and gyrotactic responses of the algae (Kessler, 1985), salinity-dependent hydrophobic adhesion properties of the Dunaliella cells (Curtain & Snook, 1983) and flocculation (Sammy, 1987). The general features of algal harvesting are reviewed by Mohn (1988).

Considering the low cell density of Dunaliella cultures it is likely that a harvesting process will have several steps. Any process which preconcentrates the alga easily maybe of benefit. In this respect the observation that Dunaliella salina sometimes aggregates on the pond surface is important. When rain results in a layer of lower-salinity or even freshwater on the surface of the pond D. salina cells accumulate at the low salinity/high salinity interface (Block et al., 1982; Borowitzka, LJ & Borowitzka, 1990). Furthermore, it is those cells with the highest β-carotene content which tend to stratify most readily. The algal cells also exhibit diurnal movement in the pond (Wangersky & Maass, 1988). It may be possible to utilize this phenomenon as part of a preliminary concentration step in a harvesting process.

Finally, it must also be recognized that different products such as dry Dunaliella powder or extracted β-carotene may require different harvesting strategies.

Extraction and drying

Another critically important aspect of Dunaliella β-carotene production is extraction of the β-carotene. The process used for extraction depends, in part, on the harvesting procedure used and on market requirements. Extraction using conventional organic solvents is efficient (Ruane, 1974a; Ruegg, 1984), but may not be acceptable to customers seeking a 'natural' product. More acceptable alternative extraction methods use hot vegetable oil (Nonomura, 1987; Potts, 1987) or liquid or supercritical gas solvents.

Harvested biomass may also be dried (i.e. spray-drying) rather than extracted and can be marketed as a β-carotene-rich supplement for human health or animal feed (Ben-Amotz et al., 1986; Avron et al., 1987; Curtain et al., 1987).

Dunaliella β-carotene production can also produce several useful by-products such as glycerol which can make up 30% of the biomass dry weight (Chen & Chi, 1981), and high quality protein meal remaining after extraction. The amino acid analysis of several Dunaliella spp. is summarized in Table 2.2 of Borowitzka and Borowitzka (1988a).

Formation and applications

β-carotene is a lipid- and oil-soluble product. As suspensions or solutions in vegetable oil it finds applications in colouring margarine, baked good, and some prepared foods (Klaui, 1982). Conversion to water-soluble or water-disperable formulations, by forming emulsion or microencapsulated beadlets extends the food applications to beverages including orange drinks, and to confectionery and further prepared foods.

Nutritional supplements can be prepared by encapsulation of oil suspensions or solutions, or by tabletting using beadlet forms. β-carotene is pro-Vitamin A, and is an excellent source of this vitamin since it is not toxic at even high doses. Because of its antioxidant and free-radical trapping properties (Burton & Ingold, 1984; Terao, 1989) β-carotene also appears to have a cancer- preventative action, especially against epithelial cancers such as lung cancer (Peto et al., 1981). Current recommended daily doses for β-carotene are around 6 mg; 20–25 mg doses are in use in the anti-cancer trials in the US and Finland. Dried Dunaliella powder is also prepared for use in animal feed supplements.

Economics

Synthesized β-carotene is sold for a minimum of US$ 300 per kg β-carotene, and at higher process depending on the formulation. 'Natural' β-carotene commands higher prices, with the highest price attainable for the nutritional supplement application. At present the market demand exceeds supply.

If a price range for formulations of β-carotene of US$ 500–1000 is assumed, and β-carotene represents 10% of D. salina biomass, production costs should not exceed US$ 50–100 per kg. In fact, costs must be significantly lower, to account for losses at each processing step, capital expense, marketing, packaging and distribution costs.

Conclusion

Although β-carotene can be synthesized or extracted from other natural sources such as carrots, D. salina is still the richest and best 'natural' source of this carotenoid. The extreme environment in which D. salina grows also makes the open-air large-scale culture of this alga much easier compared to other unicellular algae. The low cell densities achieved by the algae and their small cell size however, make harvesting more difficult and costly. Furthermore, the use of the β-carotene as a food or feed additive and a nutritional supplement means that a high quality product is required. This means that great care must be taken in the extraction and formulation steps.

Despite these difficulties there are now several commercial producers of D. salina β-carotene and a number of others are expected to come on stream in the near future. The high value of the product also means that, even with the technology available today algal β-carotene production is an economic reality.

References

Aasen AJ, Eimhjellen KE, Liaaen-Jensen S. 1969. An extreme source of β-carotene. Act. Chim. Scand. 23:2544–2545.

Aizawa K, Miyachi S. 1984. Carbonic anhydrase located on the cell surface increases the affinity for inorganic carbon in photosynthesis of D. tertilecta. FEBS Lett. 173: 41–44.

Avron M, Edelstein S, Ben-Amotz A. 1987. Feed supplement. UK Patent Application Number 2189675A.

Ben-Amotz A. 1980. Glycerol production in the alga Dunaliella. In San Pietro A (ed.) Biochemical and photosynthetic aspects of energy production. Academic Press, New York, 191–208.

Ben-Amotz A. 1987. Effects of irradiance and nutrient deficiency on the chemical composition of D. bardawil Ben-Amotz and Avron (Volvocales, Chlorophyta). J. Plant Physiol. 131: 479–487.

Ben-Amotz A, Avron M. 1982. The potential use of Dunaliella for the production of glycerol, B-carotene and high-protein feed. In San Pietro A (ed.), Biosaline research: A look to the future. Plenum Pub. Corp., New York, 207–214.

Ben-Amotz A, Avron M. 1983. On those factors which determine the massive B-carotene accumulation in the halotolerant alga D. baradwil. Plant Physiol. 72: 593–597.

Ben-Amotz A, Katz A, Avron M. 1982a. Accumulation of β-carotene in halotolerant algae: purification and characterization of β-carotene-rich globules from D. bardawil (Cholorophyceae). J. Phycol. 18: 529–537.

Ben-Amotz A, Sussman I, Avron M. 1982b. Glycerol production by Dunaliella. Experiential 38: 49–52.

Ben-Amotz A, Edelstein S, Avron M. 1986. Use of B-carotene and phytoene in the alga D. bardawil as a source of retinol. Brit. Poult. Sci. 27: 613–619.

Ben-Amotz A, Lers A, Avron M. 1988. Stereoisomers of B-carotene and phytoene in the alga D. bardawil. Plant Physiol. 86: 1286–1291.

Ben-Amotz A, Shaish A, Avron M. 1989. Mode of action of the massively accumulated B-carotene of D. bardawil in protecting the alga against damage by excess irradiation. Plant Physiol. 91: 1040–1043.

Bloch MR, Sasson J, Ginzburg ME, Goldman Z, Ginzburg BZ, Garti N, Perath A. 1982. Oil products from algae. US Patent Number 4341038.

Borowitzka LJ. (1981a). The microflora. Adaptations to life in extremely saline lakes. Hydrobiologia 8: 33–46.

Borowitzka, LJ. 1981b. Solute accumulation and regulation of cell water activity. In Paleg LG, Aspinall D (eds.), The Physiology and Biochemistry of Drought Resistance in Plants. Academic Press, Sydney, 97–130.

Borowitzka LJ, Borowitzka MA. 1989a. B-carotene (Provitamin A) production with algae. In Vandamme EJ (ed.). Biotechnology of Vitamins, Pigments and Growth Factors. Elsevier Applied Science, London, 15–26.

Borowitzka LJ, Borowitzka MS. 1989b. Industrial production: methods and economics. In Cresswell RC, Rees TAV, Shah N (eds.) Algal and Cvanobacterial Biotechnology. Longman Scientific, London, 294–316.

Borowitzka LJ, Borowitzka MA. 1990. Commercial production of B-carotene by D. salina in open ponds. Bull. Mar. Sci. *: (in press).

Borowitzka LJ, Brown Ad. 1974. The salt relations of marine and halophilic strains of the unicellular green alga Dunaliella. Arch. Microbiol. 96: 37–52.

Borowitzka LJ, Borowitzka MA, Moulton T. 1984. Mass culture of Dunaliella: from laboratory to pilot plant. Hydrobiologia 116/117:115–121.

Borowitzka LJ, Moulton TP, Borowitzka MA. 1985. Salinity and the commercial production of beta-carotene from D. salina. Nova Hedw., Beih. 81: 217–222.

Borowitzka MA. 1988. Algal growth media and sources of cultures. In Borowitzka MA, Borowitzka LJ (eds.), Micro-algal Biotechnology. Cambridge University Press, Cambridge, 456–465.

Borowitzka MA, Borowitzka LJ. 1988b. Limits to growth and carotenogenesis in laboratory and large-scale outdoor cultures of D. salina. In Stadler T, Mollion J, Berdus MC, Karamanos Y, Morvan H, Christiane D (eds.). Algal Biotechnology. Elsevier Applied Science, Barking, 139–150.

Borowitzka MA, Post F, Borowitzka LJ. 1982. The life cycle of D. salina. Australasian Soc. for Phycology and Aquatic Botany, Annual Meeting. 1982: 18.

Borowitzka MA, Borowitzka LJ, Kessly D. 1990. Effect of salinity increase on carotenoid accumulation in the green alga D. salina. J. Appl. Phycol.2: (in press).

Brown AD, Goyal A, Larsen H, Lilley RM. 1987. A salt-sensitive mutant of D. tertiolecta. A role of carbonic anhydrase. Arch. Microbiol. 147: 309–314.

Burton GW, Ingold KU. 1984. B-carotene: An unusual type of lipid antioxidant. Science 224: 569–573.

Chaumont D, Thepenier C, Gudin G, Junjas C. 1988. Scaling up a tubular photoreactor for continuous culture of Porphyridium cruentum from laboratory to pilot plant (1981–1987). In Stadler T, Mollion J, Verdus MC, Karamanos Y, Morvan H, Christiaen D (eds.). Algal Biotech. Elsevier Applied Science, London, 199–208.

Chen BJ, Chi CH. 1981. Process development and evaluation for algal glycerol production. Biotechnol. Bioeng. 23: 1267–1287.

Curtain CC, Snook H. 1983. Method for harvesting algae. US Patent No. 511 135.

Curtain CC, West SM, Schlipalius L. 1987. Manufacture of B-carotene from the salt lake alga D. salina: the scientific and technical background. Aust. J. Biotechnol. 1:51–57.

Dodd JC. 1986. Elements of pond design and construction. In Richmond A (ed.) CRC Handbook of Microalgal Mass Culture. CRC Press. Boca Rata. 265– 283.

Federov VD, Maksimov VN, Kromov VM. 1968. Effect of light and temperature on primary production of certain unicellar green algae and diatoms. Fiziol. Rast. 15: 640–651.

Gimmler H, Kuhnl EM, Carl G. 1978. Salinity-dependent resistance of D. parva against extreme temperatures. I. Salinity and thermoresistance. Z. Pflanzenphysiol. 90: 133–153.

Gimmler H, Weis U, Weiss C, Kugel H, Treffny B. 1989. D. acidophila (Kalina) Masyuk - an alga with a positive membrane potential. New Phytol. 113: 175–184.

Ginzburg M. 1987. Dunaliella: a green alga adapted to salt. Adv. Bot. Res. 14: 93–183.

Grant BR. 1968. The effect of carbon dioxide concentration and buffer system on nitrate and nitrite assimilation by Dunaliella tertiolecta. J. Gen. Microbiol. 54:327–336.

Guillard RRL, Ryther JH. 1962. Studies on marine planktonic diatoms. I. Cyclotella nana Hustedt and Detonula confervacea (Cleve) Gran. Can. J. Microbiol. 8: 229–239.

Kessles JQ. 1985. Hydrodynamic: focussing of motile algal cells. Nature 313: 208–210.

Klain H. 1982. Industrial and commercial uses of carotenoid. In Britton C. Goodwin TW (eds.). Carotenoid Chemistry and Biochemistry. Pergamon Press, Oxford, 309–328.

Loeblich LA. 1982. Photosynthesis and pigments influenced by light intensity and salinity in the halophile Dunaliella salina (Chlorophyta). J. Mar. Biol. Ass. UK. 62: 493–508.

Massyuk NP. 1965. Effect of Na, Mg, Cl and SO4 ions on growth, reproduction and carotene production in D. salina. Teod. Ukr. Bot. Zh. 22: 3–11.

Massyuk NP. 1966. Mass culture of the carotene containing alga Dunaliella salina Teod. Ukr. Bot. Zh. 23: 12–19.

Massyuk NP. 1973. Morphology, Taxonomy, Ecology and Geographic Distribution of the Genus Dunaliella Teod. and Prospects for its potential Utilization. Naukova Dumka, Kiev.

Mclachlan J. 1960. The culture of D. tertiolecta Butcher - a euryhaline organism. Can. J. Microbiol. 6: 367–375.

Mclachlan J, Yentsch CS. 1959. Observations on the growth of Dunaliella euchlora in culture. Biol. Bull. (Woods Hole) 116: 461–471.

Melkonian M, Preisig Hr. 1984. An ultrastructural comparison between Spermatopsis and Dunaliella (Chlorophyceae). Plant Syst. Evol. 164: 31–46.

Mil'ko ED. 1962. Study of the requirement of two Dunaliella spp in mineral and organic components of the medium. Moscow Univ. Vset., Biol. 6: 21–23.

Mll'ko ES. 1963. Effect of various environmental factors on pigment production in the alga Dunaliella salina. Mikrobiologya 32: 299–307.

Mironyuk VI,, Einor LO. 1968. Oxygen exchange and pigment content in various forms of Dunaliella salina Teod. under conditions of increasing NaCl content. Gidrobiol Zhournal 4: 23–29.

Mohn FH. 1988. Harvesting of micro-algal biomass. In Borowitzka MA, Borowitzka LJ (eds.), Micro-Algal Biotechnology. Cambridge University Press, Cambridge, 395–414.

Moulton TP, Burford MA. 1990. The mass culture of D. viridis for oxygenated carotenoid: Laboratory and pilot plant studies. Hydrobiologia in press:. Moulton TP, Sommer TR, Burford MA, Borowitzka LJ. 1987. Competition between Dunaliella species at high salinity. Hydrobiologia 151/152: 107–116.

Nonomura AM. 1987. Process for producing a naturally derived carotene-oil composition by direct extraction from algae. US Patent Number 4680314.

Oswald WJ. 1988. Large-scale algal culture systems (engineering aspects). In Borowitzka MA, Borowitzka LJ (eds.), Micro-Algal Biotechnology. Cambridge University Press, Cambridge, 357–394.

Peto R, Doll R, Buckley JD, Sporn MB. 1981. Can dietary beta-carotene materially reduce human cancer rates? Nature 290: 201–208.

Post FJ, Borowitzka LJ, Borowitzka MA, Mackay B, Moulton T. 1983. The protozoa of a Western Australian hypersaline lagoon. Hydrobiologia 105: 95–113.

Potts WT. 1987. Extraction of carotenoid pigments from algae. Australian Patent Number 69260/87.

Ramazanov ZM. Klyachko-Gurvich GL, Ksenofontov AL, Semenenko VE. 1988. Effect of suboptimal temperature on content of β-carotene in the halophilic alga D. salina. Fiziol. Rast. 35: 864–869.

Rao PSN, Chauhan VD. 1984. On occurrence and growth of Dunaliella from India. I. Enriched seawater for mass culture of the alga. Phykos 23: 33–37.

Ruane M. 1974a. Extraction of caroteiniferous material from algae. Australian Patent Number 487018.

Ruane M. 1974b. Recovery of algae from brine suspensions. Australia Patent Number 486999.

Ruegg R. 1984. Extraction process for beta-carotene. US Patent Number 4439629.

Sammy N. 1987. Method for harvesting algae. Australian Patent Number 70924/87.

Semenenko VE, Abdullayev AA. 1980. Parametric control of B-carotene biosynthesis in D. salina cells under conditions of intensive cultivation. Fiziol. Rast. 27: 31–41.

Siegel BZ, Siegel SM, Speitel T, Waber J, Stoeker R. 1984. Brine organisms and the question of habitat-specific adaptation. Origins of Life 14: 757– 770.

Teodoresco EC. 1905. Organisation et development du Dunaliella nouveau genre de Volvocaceae-Polyblepharidee. Botanisches Zentralblatt, Beiheft 18: 215–232.

Terao J. 1989. Antioxidant activity of β-carotene-related carotenoid in solution. Lipids 24: 659–661.

Wangersky PJ, Maass L. 1988. Diurnal behaviors of cultures of D. tertiolecta. J. Plankt. Res. 10: 327–329.

PROCESSING AND EXTRACTION OF PHYCOCOLLOIDS

JI MINGHOU

Institute of Oceanology, Academia Sinica
Qingdao, China

Phycocolloids refer to those polysaccharides extracted from both freshwater and marine algae. Until now, only the polysaccharides extracted from marine red and brown algae, such as agar, carrageenan and algin are of economic and commercial significance, since these polysaccharides exhibit high molecular weights, high viscosity and excellent gelling, stabilizing and emulsifying properties. They are also extracted in fairly high amount from the algae. All these polysaccharides are water soluble and could be extracted with hot water or alkaline solution.

The different steps in processing and extraction of phycocolloids used in different factories are essentially based on the same principle. However, each factory usually guards as its own trade secrets the details on equipments used and the manufacturing techniques and process. The common processes adopted in most factories for extracting and processing agar, carrageenan and algin are discussed.

A. Agar

1. Development

Some 300 years ago, presumably in 1658, a Japanese innkeeper Tarozaemon accidentally discovered the method of producing dry agar. In 1919, Matsuoka attempted to make agar in California. Now the biggest agar factory in U.S.A. is the American Agar Company in San Diego, California. During the second world war production of agar in Portugal, Spain, Mexico, South Africa, South America, New Zealand, Australia and France also commenced.

In northern China the agar factories produce strip agar in winter relying on the natural freeze-thaw condition; in other seasons they use the diffusion and press techniques to make agar powder. In South China, all the agar makers use the mechanical freezing process to produce strip agar.

2. Processing of agar

Agar is now primarily produced by two main processes: freeze-thaw and press dehydration. The former is divided into two types: natural and mechanical. Nevertheless, both follow the same fundamental principle of extraction and clarification.

The main steps in processing agar from agarophytes may be summarized as: (1) Extraction of agar with hot water; (2) Filtration to eliminate the weed residues; (3) Concentration and purification (freeze-thaw or gel-press); (4) Drying.

a. Gelidium agar

The flow sheet of Gelidium agar production is shown in Fig. 1.

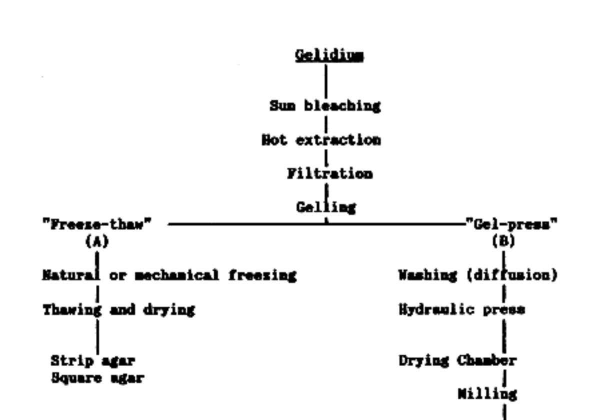


Fig. 1. Flow sheet of Gelidium agar production

The advantage of the gel-press process is that it omits the freeze-thaw cycle, and the final product is always in powder form. In the Orient, the freeze-thaw process is mainly to produce the square agar or strip agar.

Because agar from Gelidium is always of high grade quality, there is no need for alkali modification as in Gracilaria. In modern factories the hot extraction is performed in a pressure cooker instead of the open steam cooker, favouring the extraction of agar. In Japan and China both types of processing (A and B in Fig. 1) are employed, but in Japan, other species of red seaweeds besides Gelidium are mixed as the subsidiary material while in China, Gelidium is always singly used to produce high quality agar.

b. Gracilaria agar

As the culture of Gracilaria is easier, its growth faster and its price cheaper than that of Gelidium, most of the agar makers nowadays utilize Gracilaria as the main agarophyte. The manufacture of Gracilaria agar is generally similar to that of Gelidium, but since Gracilaria contains a considerable amount of highly sulfated galactan (the precursor of agarose) varying with species, growing season and location, an alkali treatment process for Gracilaria is an extremely important measure to improve the quality of agar product. Fig. 2 shows the plant flow sheet diagram of Gracilaria agar production.

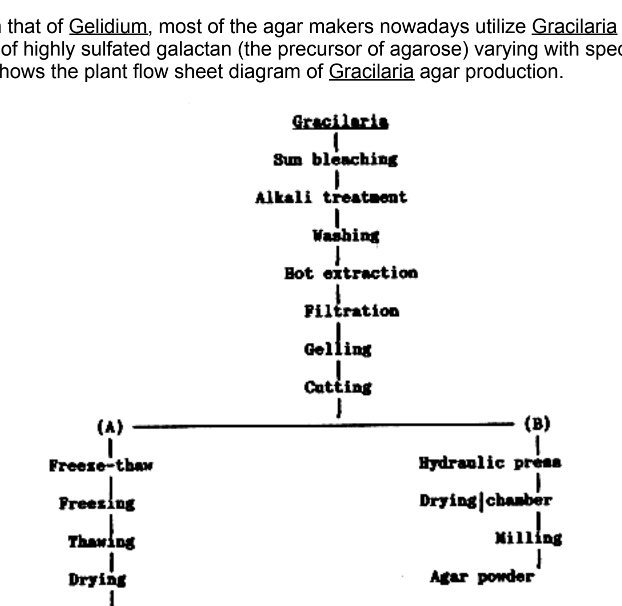


Fig. 2. Flow sheet of Gracilaria agar production

Alkali modification

In 1936 Yanagawa discovered that the alkali treatment of agar from Gracilaria could enhance the gel strength of the product, this method has been extensively used by Gracilaria agar makers. Up to 1961 Rees postulated that the alkali could eliminate the 'kinks' (sulfation at C- 6 of 1,4-linked-L-galactose residues) existing in the agar molecules, and 3,6-anhydro rings are formed, resulting in the enhancement of gel strength of the agar produced. The agar makers usually use different concentrations of alkali solution to treat the Gracilaria algae according to the species and the quality of the algae collected. In general, the Gracilaria weeds are treated with 6–7% NaOH solution for 1–2 hours at 70–90 °C (Table 1). For some species, which contain much highly sulfated galactans, a higher concentration of alkali is needed.

Table 1. Alkali treatment for Gracilaria algae.

Location of collection	NaOH concentration used	Temperature of treatment (°C)	Time of treatment (hr)
Argentina	6.0	50–60	1.0
Chile	6.0–7.0	88–90	2.0
Mexico	6.0	90	0.5–1.0
Africa	6.0	70	1.0–1.5
India	20.0	70	1.0
Taiwan	10.0	85–90	1.0
Portugal	4.0–5.0	60	1.0

For Porphyra haitanensis, which is used in considerable amount in Fujian Province, China, due to its high content of the precursor of agarose, a higher concentration of alkali (such as 10–20%) is needed and a higher temperature of treatment (90–100 °C) than for Gracilaria should be used. By such treatment the agar exhibits almost pure agarose skeletal structure shown by both chemical and ^{13}C-NMR analysis. The exact techniques of alkali treatment are secrets closely guarded by the makers.

c. Agarose

Agarose, a main product derived from the commercial agar product, recently has been widely used in the biochemical fields. The reason is that its physical and chemical properties approach those of an ideal gel matrix for diffusion and electrokinetic movement of biopolymers. A good number of agarose products has appeared in the market, such as BioProducts SeaKem agarose, SeaPlaque agarose, NaFix glyoxyl agarose, etc, produced by FMC & Co.; Sepharose series of gel filtration medium by Pharmacia Co., and Bio-Gel products by Bio-Rad Laboratories.

There are various methods for manufacturing the agarose, but among these the CPC, DEAE-Cellulose and Polyethylene glycol (PEG) methods are applicable.

1. CPC method: CPC or hyamine is a cationic polymer, which may react with highly sulfated galactan in agar forming the precipitate. The addition of a small amount of lambda- carrageenan, in this case a highly sulfated anionic polymer, may increase the bulk of the quaternary ammonium salt precipitate, and thus facilitate the removal of sulfated galactan by co-precipitation.
2. DEAE-Cellulose method: An adequate amount of anionic exchange resin DEAE-cellulose powder are added into the agar solution and the mixture is stirred at 80°C. The sulfate galactan in agar is adsorbed by the anionic resin and removed by filtration. The filtrate is sent to gelling, freeze-thaw, alcohol dehydration, drying and milling to agarose powder.
3. PEG method: 7–20% PEG (mol. wt. 6,000) and 1% NaCl are added into the boiled agar solution. The agarose is precipitated, isolated and dehydrated by acetone.

B. Carrageenan

1. Development

Although the application of Irish moss extract was reported in 1837, its formal production was initiated only in the 1930's in the United States. Now, the main carrageenan producing countries are U.S.A., Denmark, France, Japan, Spain, China, Korea, Brazil, Philippines, etc.

In China, carrageenan production started in the 1970's in Hainan Island using Eucheuma gelatinae as the raw material; and later Hypnea sp. was utilized as well.

Carrageenan, like agar, is now extensively used in the food industry. Owing to its superior characteristics in dairy food product and biotechnology, its annual production is rapidly increasing and has recently exceeded that of agar. Recent estimates place the annual production of carrageenan over the world at about 15,000 tons, including about 600 tons annually in China.

2. Processing of carrageenan

By the chemical studies on the carrageenan structure it has been known that carrageenan from different species of carrageenophytes essentially may be divided by the structural feature into the Beta, Kappa and Lambda families. Again they are subclassified into 13 types depending upon the position of sulfate groups on (1 → 3) and (1 → 4)-linked D-galactose residues. But among these only kappa, iota and lambda carrageenans are of commercial significance, because they are the main components in carrageenophytes, which have abundant sources, and possess the properties applicable in food, pharmaceutical and other uses. Kappa-carrageenan is the main product, widely used in food industry as a gelling agent. Recently iota-carrageenan has also been used in food and other industries, owing to its peculiar properties which are different from that of Kappa's. Lambda-carrageenan is extensively used in food products as the stabilizer and emulsifier due to its non-gelling and high viscosity properties. With their different properties, their processing and extraction differ somewhat from each other.

a. Kappa-carrageenan

This family contains about 35% 3,6-AG and 25% sulfate, and being more hydrophobic, the freeze-thaw and gel-press processes used in Gracilaria agar production are quite applicable to K-carrageenan processing, as shown in Fig.3.

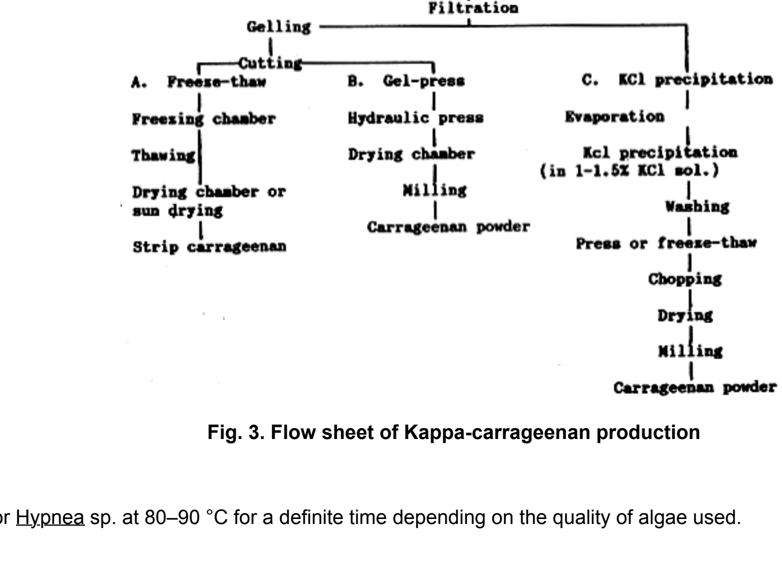


Fig. 3. Flow sheet of Kappa-carrageenan production

Alkali modification

Usually 5–10% NaOH solution is used to treat Eucheuma sp. or Hypnea sp. at 80–90 °C for a definite time depending on the quality of algae used.

KCl precipitation process

Some carrageenan makers apply KCl precipitation process (Fig. 3 C) for K-carrageenan production from Furcellaria sp. or Eucheuma sp. In this case, the filtrate after hot extraction should be evaporated with the double-effect evaporator to reduce the volume of filtrate and then the filtrate is extruded through spinnerets into a cold 1–1.5% KCl solution. The resulting gelled threads are washed with KCl solution, followed by pressing, drying and milling to K-carrageenan powder.

C. Lambda-carrageenan

Lambda-carrageenan contains about 35% sulfate and 0% 3,6-AG, exhibits no gelling ability at all and is more hydrophilic. Thus it could be dried by using drum dryer or alcohol precipitation process. The former will cause serious degradation of the product, so that the latter process is widely used. Propyl alcohol or ethyl alcohol is used as the dehydrating agent (Fig. 4). Iota-carrageenan has gelling properties in the presence of calcium ions but contains 30% 3,6-AG and 32% sulfate, and thus more hydrophilic than K-carrageenan. It is also difficult to be produced by the freeze-thaw or gell press processes so that it is also produced with alcoholic precipitation as, with lambda-carrageenan.

Gigartina sp.
Eucheuma sp.
|
Sun bleaching
|
Washing
|
Hot extraction
|
Filtration
|
Evaporation
|
Alcohol precipitation
|
Centrifuge
|
Drying
|
Milling
|
Iota- or Lambda carrageenan powder

Fig. 4. Flow sheet of Iota- and Lambda-carrageenan production

Evaporation and alcohol precipitation

After hot extraction the pH of the alkaline liquor is adjusted and subjected to coarse and fine filtration. The filtrate is then concentrated with the double-effect evaporator to reduce the water volume.

D. Semi-refined or semi-processed carrageenan (Fig. 5)

The semi-processed carrageenan is produced simply by alkali treatment of Eucheuma cottonii and drying in the farm on the shelf. A basket of seaweeds is immersed and cooked in hot aqueous KOH at 100 °C and then soaked in fresh water to extract the alkali. The product is dried and ground to powder. By this process the ratio of process water to product is minimized, thereby reducing the cost of the product. This product can usually substitute for extracted carrageenan where a little cloudiness due to the small amount of cellulose present does not interfere.

Eucheuma cottonii
|
Cutting
|
Alkali treatment
(8.5% KOH)
|
Rinsing
|
Sun drying
|
Milling
|
Semi-processed carrageenan product

Fig. 5. Diagram of semi-processed carrageenan production

E. Algin

1. Development

In 1881 Stanford first discovered algin, a polysaccharide from a brown seaweed Laminaria stenophyllum. In 1927, Thornley set up a company to produce alginate in San Diego, U.S.A., which in 1929 was reorganized into the Kelco Company. Alginate production was initiated in U.K. by Alginate Industries Ltd. in 1934–1939. In the 1980's Kelco and Alginate Industries were acquired by Merk & Co. in U.S.A. and now produce about 70% of the world's alginate. The next largest producing country is China, followed by Norway, France, Japan, etc.

In China, algin production was initiated in 1957 in Qingdao from a wild brown seaweed resource, Sargassum pallidum. From the late 1960's Laminaria japonica had replaced Sargassum since the Laminaria was cultivated on a large scale along the coast of China from Dalian to Fujian Province with the maximum annual production of about 270,000 tons dry weight in 1979.

Alginates have a wide application in various industries, but mainly in food industries because of their high viscosity, stabilizing, thickening and gelling abilities. In addition, alginates are extensively used in textile, paper, welding and the pharmaceutical industries.

Recent estimates place the annual production of alginate over the world at about 35,000 tons. China contributes 10,000 tons.

2. Processing of alginate

The rationale of processing and extraction of alginates in various factories are essentially akin to each other, although the exact processing techniques and equipments used are somewhat different and guarded as trade secrets. There are two main processes in the manufacture of alginate: calcification and acidification (Fig. 6). Many algin makers tend to adopt the calcification process because it is easy to dehydrate the product and gives a high yield.

In the extraction and clarification of alginate, alkali and acid are unreasonably and repeatedly used:

$$M(Alg)_2 + 2Na^{+} \xrightarrow{OH^-} 2NaAlg + M^{2+} \quad (1)$$
$$Ca(Alg)_2 + 2H^{+} \longrightarrow 2HAlg + Ca^{2+} \quad (2)$$
$$HAlg + Na^{+} \xrightarrow{OH^-} NaAlg + H^{+} \quad (3)$$
$$2NaAlg + Ca^{2+} \longrightarrow Ca(Alg)_2 + 2Na^{+} \quad (4)$$
$$NaAlg + H^{+} \longrightarrow HAlg + Na^{+} \quad (5)$$
$$Ca(Alg)_2 + 2H^{+} \longrightarrow 2HAlg + Ca^{2+} \quad (6)$$
$$HAlg + Na^{+} \xrightarrow{OH^-} NaAlg \quad (7)$$

Except reaction (4), all other reactions are acidic or alkaline reactions.

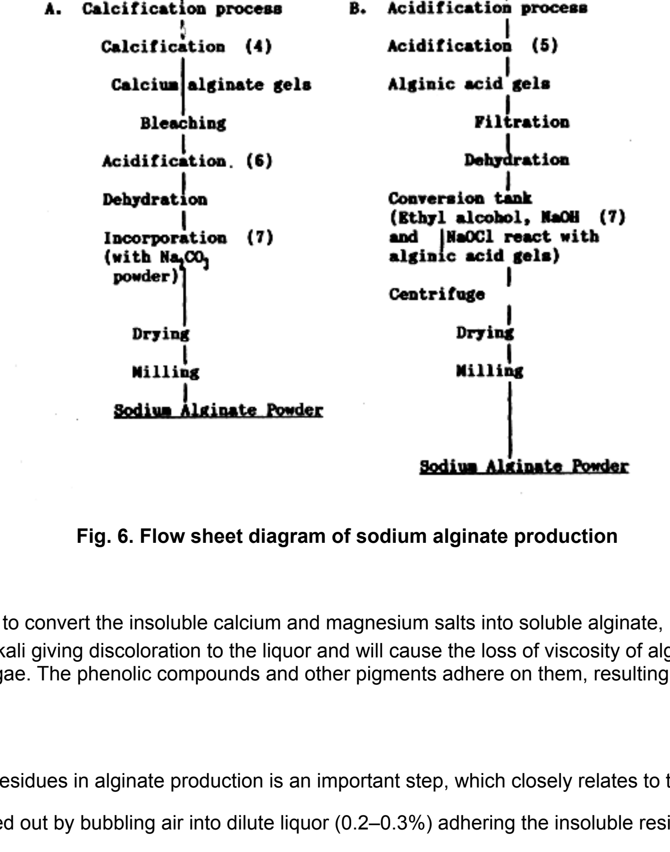


Fig. 6. Flow sheet diagram of sodium alginate production

Pretreatment

Among some algin makers, diluted acid is used to pretreat the alginophyte to convert the insoluble calcium and magnesium salts into soluble alginate, Fig 6 (2), facilitating the ion exchange of H^+ with Na^+ of Na_2CO_3, and to remove the phenolic compounds which will form brownish products with alkali giving discoloration to the liquor and will cause the loss of viscosity of alginate. Most makers including those in China now use formalin solution instead of acid to pretreat the alginophyte to fix the proteinous matter in algae. The phenolic compounds and other pigments adhere on them, resulting in decolorization of the final alginate product and preservation of high viscosity.

Clarification

Separating the viscous sodium alginate solution from the finely dispersed residues in alginate production is an important step, which closely relates to the quality of the product.

1. Floatation: This process, widely used by many algin makers, is carried out by bubbling air into dilute liquor (0.2–0.3%) adhering the insoluble residues to the floc and floating onto the surface of the liquor.
2. Filtration: The quality of alginate to some extent depends on the filtration equipment used. Filter press is used in most alginate plants; a coating of diatomaceous earth as filter aid will effectively eliminate the small suspended residues in liquor. Other algin makers use the Dorr-Oliver vacuum drum filter which is a rotary precoat vacuum filter. The rotary drum is coated with a 2–3 cm layer of precoat material, preferably perlite. After 9–10 hrs, most of the precoat would be removed by the scraper.
3. Dehydration: The alginic acid gels are dewatered by screw press to 25% or more solids, to which ethyl alcohol and concentrated NaOH solution (40%) and NAOCl solution are introduced. In some makers, the gels are dewatered by hydraulic press to about 20% solids content.

According to various applications the algin makers produce alginic acid and its salts: ammonium alginate, sodium alginate, potassium alginate and calcium alginate. Of these the main product is sodium salts, since it easily dissolve in water and exhibits high stability.

3) Processing of propylene glycol alginate (PGA)

Propylene glycol alginate (PGA) is an important derivative of alginic acid, which is manufactured by reacting alginic acid gels and propylene oxide under pressure (Fig. 7), and could be used in acidic solutions, largely extending the alginate application in food.

Alginic acid gels
|
Dehydration
|
Partial neutralization
|
Esterification
|
Washing with alcohol
|
Drying
|
Milling
|
PGA Powder

Fig. 7. Flow sheet of PGA production

Alginic acid gels with 45–55% moisture content are used to react with gaseous propylene oxide (mole ratio 1:3) in a pressure vessel at 45–60 °C for 8 hrs, giving a final product with about 80% degree of esterification and a pH of 3.8–4.6. A good esterification may be achieved with a low neutralization (0.4%), the solids in an alginic acid gels being as low as 20–34%. The reaction runs generally at 75–85 °C for 2 hrs.

PGA is widely used in acidic drinks or dairy products as stabilizer, and its solution remains unchanged to about pH 3.

VARIOUS ASPECTS OF FUNDAMENTAL RESEARCH, BIOTECHNOLOGY AND INDUSTRIAL TRANSFER USING MICROALGAE

J. P. DUBACQ

Laboratoire des Biomembranes
Ecole Normale Superieure
U.R.A. C.N.R.S. 311 Rue d'Ulm
75230 PARIS Cedex 05, FRANCE

In recent years the production of algae in the world has reached more than 2 million tons. Algae are used either directly as total foodstuff (i.e. Spirulina) or as the source of products for the food industry (i.e polysaccharides) or more specific material to get coloured proteins. However many other compounds appear very interesting such as proteins, lipids, pigments, and others.

In order to improve the productivity of the algae culture we support the idea that much more fundamental research is now necessary to reach a biotechnological approach of these goal. The objectives of such research depend on the product that we want to improve. For total consumption, mass production appears to be the main purpose. For polysaccharides, the quality of the product is much more important and mass production is less emphasized. For the more specific products found in the algae, two ways are offered: the specific algae is grown only for that product, or the compound can be a by-product of another industrial processing. In any of these cases improvement of the productivity must be carefully followed in order to obtain the maximum quality of both the main products and by-products.

This brief paper focuses on several aspects of fundamental research on microalgae which are presently intended by a group of laboratories in France with the final purpose of a biotechnological transfer to industry. The three main lines of fundamental research that are investigated are the following:

Analytical research with accurate technics which reveal details of the chemical composition and can assume purity of the products. (An example will be given by the HPLC-diode array spectrophotometric analysis of pigments in Spirulina which reveals traces of rare carotenoids). A lot of interest has now turned to phycobiliproteins, not only as a source of protein food for a complementary diet like in Spirulina but also for medical and immunological utilization. In fact phycobiliproteins are parts of protein complexes which contain different proteins associated with pigments with different properties. One can see from an example that the organization of this complex is very complicated and consequently any biotechnological manipulation of this structure in order to get a more specific composition in phycocyanin or phycoerythrin requires much more work on the synthesis and assembly of this structure. Such research on physiology and genetic control are beginning now. On the other hand new and very interesting products can appear such as the lipid polymer resistant cell walls which will be described.

Physiological studies are classical in literature. They concern essentially the modifications of the productivity relative to environment factors. However it seems also improtant to underline that in some cases such modifications can result only in negligible changes in the composition and productivity. Much more specific physiological studies can be done to improve the production of a specific product by growing the algae with the addition of a low-cost substrate. (Assays of lipid synthesis in Spirulina or other cells will be given). Another possibility of alteration of the composition of algae comes from studies of the photosynthesis process and more specifically, photo-inhibition. During photoinhibition some changes in the carotenoids can occur due to protective oxidation. One could use such physiological processes to get a specific increase of one or another product.

Molecular biology concerns the studies of the genetic control of cell composition and metabolism. Up to now it is a scientific domain welldeveloped for higher plants where, in combination with biotechnology, it has resulted in very interesting progress in food production. For work on algae, this is far less developed although the knowledge of the cyanobacterial (blue-green algae) genome is more advanced. This type of science is just beginning for brown and red algae. It reveals very interesting possibilities for fundamental research as well as for future applied works. For example it shows essential differences from higher plants for the localization and regulation of the synthesis of chloroplast proteins. This might be of great importance for the manipulation of the phycobiliprotein composition of cells. This type of work must be developed.

These three main lines of fundamental research are developed at the same time as applied research; they promote each other as often as possible. Application by industry of results from fundamental research needs biotechnology and industrial transfer, which are necessary in order to promote a favourable situation for the discoveries from the type of research mentioned above.

Biotechnology is under development. Two specific lines of efforts are described here. The first consists of preparing protoplasts from brown algae. As anyone knows this step is very important in realizing a programme of genetic manipulation and introduction of foreign genes in a living organism. It has been a clue for the use of in vitro technics in higher plants. We hope that it will develop rapidly in algae and that it will open a new field of possibilities. The second one consists of a culture technology which aim to be as much controlled as possible. In that way, assays of algae incorporated into alginate are successful. They can promote some lipid productivity. Another technology for controlled culture is the tubular system, which gives a high yield.

Industrial transfer is now realized for the production of some substance such as pigments, and protein preparation the quality of which is guaranteed by the previous efforts of fundamental research. Constant productivity and composition is reached by this technique. It leads to the preparation of large quantities of pure products. (An example will be given for the large scale production of Porphyridium in tubular cultures with extraction of coloured products).

In conclusion, we hope that more research will be done in the near future and that the coordination of these efforts with industrial purpose will soon promote the use of algae -- the initial primary producer of organic compounds -- as one of the main biological resources in the world.

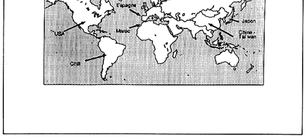
PRODUCTION, PROPERTIES, AND USES OF ALGINATE, CARRAGEENAN AND AGAR

Dr.Ulrich Sachsenhöfer

Consultant
Organisation Ressources Humaines
Rue Jean Monnet, Parc d'Activités
Nantes cedex 03 France

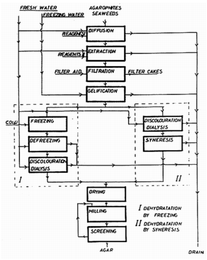
Introduction

Phycocolloids are commercially important hydrophilic colloids (water-soluble gums) which once as marine material in numerous species of red seaweeds (Rhodophyta) absorbed they form a structural hydrate analogous to that of cellulose in land plants. Chemically they are long-chained polymers. Due to their high water-holding capacity they are used as gelling agents, in thickening and stabilizing products. In the present they offer food and non-food products, for example in food, pharmaceuticals, cosmetics, paper, textiles, paints, explosives, ceramics, photography, welding rods, and in the production of other phycocolloids. Alginates are used in food products, pharmaceuticals and cosmetics, and gelcrete acids and as wash-coat from corks. Alginates differ from other phycocolloids in the reason Agarose and Agar are more soluble in water, forming gels at lower temperatures. In



EXTRACTION PROCEDURE

AGAR FABRICATION DIAGRAM



NEW EXTRACTION PROCESS FOR BACTERIOLOGICAL QUALITY AGAR-AGAR FROM SESQUIPEDALE GELIDIUM RED ALGA
I - DISCOLOURATION OF EXTRACTION JUICES

Eliminating chromophores from sesquipedale geledium red alga of native β-carotene or degradated phycobiliary group, was carried out in the presence of chloride macroporous anionic resins, most efficient system requires a continuous system involving a compact resin bed under ascending current. Resins are regenerated by a sodium chloride solution and are not affected by successive cycles.[1,2]

NEW EXTRACTION PROCESS FOR
THE BACTERIOLOGICAL QUALITY AGAR-AGAR
II - ELIMINATION OF THE MINERAL CHARGE

The endogenous mineral charge from sesquipedale Gelidium alga is studied. This charge released in the agar-agar extraction juice, accounts for the high mineral content in agar-agar extraction juices. Demineralisation is carried out by ion-exchange resins. Sodium gel resins prove to be the most efficient. A sodium/heavy cation exchange eliminates major part of heavy cations. Gelling the agar-agar solution permits its separation by mechanical pressing-out or freezing-defrosting. The caking or agar-agar micells recovered are almost rid of all sodium chloride released in water, whilst conforming to bacteriological agar-agar quality in the residual mineral composition. Resins are regenerated by simple sodium chloride solution without being affected by successive cycles.[1,2]

R. LEBBAR, A. ZIOUANI, M. DELMAS*, and A. GASET

Laboratoire de Chimie des Agroressources
Ecole Nationale Supérieure de Chimie de Toulouse
Institut National Polytechnique de Toulouse
118 route de Narbonne, 31077 Toulouse Cedex, France

* To whom correspondence should be sent

APPLICATIONS

The major role of hydrocolloids in food preparations is based on water-binding capacity and their ability to modify the rheological behaviors in order to obtain a desired functionality suited to the application.

The selection factors will be interdependent with the conditions of use:

- pH-value of the system,
- Presence of electrolytes,
- Heat-treatments,
- Stability to storage.

All colloids do not perform in the same manner to these different parameters.

HEAT TREATMENTS

Apart from pectins; which are partially depolymerized, most hydrocolloids withstand heat treatments of pasteurization and sterilization when used in system at pH-values near neutrality.

STABILITY TO STORAGE

It depends on the modification liable to occur in the macromolecule associations. Too great junction zones will lead to syneresis. The latter can be avoided by the addition of macromolecules which induce perturbations in these multiple associations.

IN ACID SYSTEM

In an acid system hydrocolloids, apart from pectins and xanthan gum display a propensity for hydrolysing as a result of the combination temperature/duration. In such a process acid should be added finally which reduce depolymerization.

ELECTROLYTES INTERACTIONS

These interactions have been described with regard to gelation and particularly to the gelation of alginates and pectins. When they are used in presence of calcium, these electrolytes assist in creating junction zones required for gelation but sometimes they should be sequestrated to allow the colloid to be hydrated.

Hydrocolloids are used in foods essentially as:

- THICKENING
- GELLING
- STABILIZING

AGENTS

Thickening Gelling

Very soluble hydrocolloids which show no capacity to create junction zones:

Galactomannans,
Lambda Carrageenan.
Alkaline Alginate.
Nanthan gum.

Some typical uses in foods:

- Sauces, salad dressings and related products,
- Soups and thick soups,
- Custards type "dessert-creams",
- Binding agents for meat products.
- Instant products,

The major properties of this type of hydrocolloids are as follow:

hot water soluble. Form gels when cooled to room temperature (thermally reversible gels).

cold water soluble. Form gels in presence of reactive salts.

hot water soluble. Form gels in presence of acid (non-thermoreversible gels). Because of the wide range of possible variations exhibited by the intramolecular associations, textures can be modulated at will to obtain the desired functionality. For this purpose, combinations of colloids are often selected.

Thermally reversibles gels

Low-methoxy pectins.
κ-carrageenan with gels rigid in texture.
ι-carrageenan with resilient and thirotropic gels.
κ-carrageenan and locust bean gum with a cohesive and resilient texture.
Gelatin

Some typical uses in foods:

- Milk-gels type flans.
- Flavored milk-gels type gellified milks.
- Water-gels, low-sugar jams and coverings.
- Meat preserves (canned meat), pet-foods, aspics.
- Confectionery.

Gelling Stabilizing

Light or non-thermoreversible gels

- Alkaline alginate in presence of a low-reactive acid or in presence of a calcium salt. According to the rate of use of Ca^{++}, the gel may be slightly thermoreversible or on the contrary completely irreversible.
- High methoxy pectins (HM pectins) in presence of acid and sugar.
- Low-methoxy pectins (LM pectins) in presence of Ca^{++} (saturation of the pectic gel).

Some typical uses in foods:

- Jams and Jellies.
- Jellified confectionery: fruit jellies,
- Meat-preserves (canned meats), pet-food.
- Restructured foods (reformed fruits, various food analogs).

The separations between the various phases of a mix can be avoided by:

- a thickener which will act by an increase in viscosity,
- a gelling agent at low usage level apt to create a three-dimensional network.
- or a combination of thickeners and gelling agents.

Some typical uses in foods:

- Emulsified sauces, salad dressings,
- Ice-creams and related products,
- Chocolate milks,
- Fruit beverages.

Pastagar A — Pastagar B
Powdered bacteriological agars

Pastagars A and B are specially purified for the preparation of bacteriological culture media.
They conform to the standards of the American Pharmacopoeia, (U.S.P. XVIII).

Directions for use *Pastagar A is an american type agar with weak gelling ability.* Used at concentrations of 1.5 to 1.7 % the agar is firm and clear. It can also be used at lower concentrations (0.1 to 0.6 %) for the detection of motility and for growing anaerobic and micro-aerophilic organisms.

Pastagar B is a european type agar with strong gelling ability. Used at concentrations of 1.2 to 1.4 %, the agar is firm and clear. It can also be used at lower concentrations (0.05 to 0.5 %) to study motility and to grow anaerobic and micro-aerophilic organisms. The pH of a 1.5 % solution in distilled water is 7.2 ± 0.3; those media prepared with one of the two Pastagars (A or B) are therefore near neutrality.

Quality control Quality control ensures that all batches of Pastagars A and B conform to a predetermined standard. This is a continuous process, testing the purity of the raw materials, surveying the manufacturing procedures, and carrying out physical, chemical, bacteriological and performance tests.

Average characteristics

	Pastagar A	Pastagar B
Appearance	Cream-white powder	Cream-white powder
Density	0.6 to 0.7	0.6 to 0.7
Odour	Slight, non-putrid	Slight, non-putrid
Gel strength before and after autoclaving Transparency(Nephelos Coleman) before and after autoclaving	*500 to 700 g/cm*	*Greater than 700 g/cm*
	Less than 50 NC	Less than 50 NC
Colonmetry:		
655 nm filter	0.010 to 0.020	0.010 to 0.020
525 nm filter	0.020 to 0.050	0.020 to 0.050
430 nm filter	0.050 to 0.150	0.050 to 0.150
pH:		
Befor autoclaving	7.2 = 0.3	7.2 = 0.3
After autoclaving	7 = 0.6	7 = 0.6
Hydration	Less than 12 %	Less than 12 %
Ash	*Less than 7 %*	*Less than 3 %*
Granulometry:		
Sieve n° 18	0	0
Sieve n° 35	Less than 5 %	Less than 5 %
Sieve n° 60	Less than 25 %	Less than 25 %
Sieve n° 150	Less than 50 %	Less than 50 %
Sieve n° 350	Less than 25 %	Less than 25 %
Sieve n° > 350	Less than 5 %	Less than 5 %
Precipitation after autoclaving	None	None
Melting temperature	89 = 4 °C	89 = 4 °C
Gelling temperature	35 = 5 °C	35 = 5 °C
Insoluble material	None	None
Contamination with thermophilic spores	None	None
Growth tests	Satisfactory	Satisfactory

Principales applications des colloïdes algaux.
(Source: BIOFUTUR, Mars 1990)

	Domaine d'application	Fonction	Pourcentage de la demande
ALGINATES	TEXTILE	épaississant pour la pâte contenant le colorant	50%
	AGRO-ALIMENTAIRE	épaississant, gélifiant, émulsifiant, stabilisant, rétenteur d'eau	30%
	PAPIER	film protecteur lors de la fabrication et de l'encrage	6%
	BAGUETTES DE SOUDURE	enrobage (contrôle des conditions thermiques et gazeuses au contact la soudure)	5%
	PRODUITS PHARMACEUTIQUES	agent dispersant pour comprimés, épaissant, gélifiant	5%
	AUTRES		4%
CARRAGHENANES	PRODUITS LAITIERS	gélifiant, epaissant, stabilisant (interactions avec les protéines)	52%
	GELS AQUEUX (desserts, nappages…)	gélifiant	16%
	AGRO-ALIMENTAIRE	stabilisant d'émulsions	10%
	AUTRES	rétenteur d'eau	
	NON ALIMENTAIRE (dentifrices, diffuseurs, cosmetiques)	gélifiant, viscosifiant en particulier en association avec ces polyols	22%
AGARS	AGRO-ALIMENTAIRE	puissant gélifiant, epaississant	58%
	PHARMACIE & TECHNIQUES BIOCHIMIQUES	excipient, axatif, agent dispersant, agent ce separation (agarose)	14%
	BACTERIOLOGIE	support de culture	28%
	DIVERS (CULTURE *IN VITRO*)	support de culture	non estime

Uses of Agar

Food Industry (58%)

Strong gelling agent, thickener, stabilizing agent

- **jellies and candies**
- **marmalade**
- **mitsumame production**
- **bakery
**
- **fruit jelly preparations**
- **yoghurt**
- **soft boiled sausages in meat industry**
- **canned products**
- **chicken, tongue, fish in gelatin<li>**

Pharmacy

- **gel forming agent, excipient**
- **smooth laxative**
- **stabilizer, dispersive**

Biotechnology

Bacteriological Agar (28%)

- **Deionized agar**
- **Culture Media**
- **Bacteriology, Mycology**
- **Insects Media**
- **In vitro culture vegetables, flowers, trees**
- **Agarose**
- **Biochemistry**
- **Immunology**
- **Genetic engineering industry**
- **Beads**

MARINE ALGAE UTILIZATION IN FOOD AND PHARMACOLOGY

ANNETTE ALFSEN

Directeur de Recherche,
Centre National de la Recherche Scientifique.
U.P.R. 64 CNRS, 45 rue des Saints Pres 75006 Paris.

The shortage of animal proteins is one of the most serious problems facing the population of Asia. Thus, finding a source of vegetal proteins and increasing their nutritional value should be an important goal for the Asian countries. Marine algae used as food for a long time in Asia are now largely cultivated by some countries and could be a very large source of protein as known from recent studies.

In order to develop and extend the use of algal protein in human food and animal feed, three main steps should be followed:

a. increase the total production of marine algae most commonly used as food such as Porphyra, Undaria, Laminaria and Gracilaria.

b. genetically improve the quality of the proteins obtained from the different algae.

c. process the harvest in order to obtain a product easy to use, keep or export to other Asian countries and those outside the region.

To accomplish the above, more has to be known about the biology of algae and their relation with the external medium. Our group in Paris, in collaboration with the Academia Sinica's Institute of Oceanology in Qingdao, China has been conducting fundamental research on marine algae, mainly on the internalization and intracellular traffic of macromolecules like proteins.

Using our experience in animal and plant cell biology, we have described the process of endocytosis in two species of pluricellular algae, namely, the green alga, Ulva lactuca (Ulvophyceae), and brown alga, Laminaria digitata (Pheophyceae). Such a process has been largely studied in animal cells and is known to govern all the exchanges of the organism, the organs and the cells with their external medium. It is also responsible for the intracellular traffic of the internalized molecules and therefore for the growth and multiplication of the cells. The cell organelles involved in this process are membrane organelles called coated pits (CP) and coated vesicles (CV), because of their being surrounded with a lipid vesicle of a fuzzy protein coat, which is very characteristic. The demonstration of the existence of the same process involving similar organelles and mechanisms in the vegetal (particularly in marine algae) as in the animal kingdom, allowed us to suggest a common role for these organelles in the cells throughout the evolution.

Biochemical analyses of whole algae and of algal coated vesicles demonstrates the presence of phospholipids (PE, PC, PS, PI and PG) which are all present in mammalian CV. From different sources of animal tissue and different methods of preparation, 150–430 nmoles of lipids phosphorus/mg protein have been reported in the CV. The values obtained for L. digitata and U. lactata CV enriched fractions, which are 312 nmoles and 103 nmoles /mg of protein respectively, were in the same range. The amino sugars GalNAc and GlcNAc represented 25% of the total carbohydrate content detected and measured in CV from the two species, after acid hydrolysis of the samples. It suggests the presence in these organelles of a high content of glycolipids or of glycoproteins. Indeed, in the whole cell extract of Phaeophycae and Chlorophycae which exhibited a high content of glycolipids, neither GalNAc nor GlcNAc was detected. The detection of these sugars only in CV suggests involvement of these organelles in molecules segregation and concentration in seaweeds as well as in animal cells. As in other plant cells, algal CV may therefore be involved in polysaccharides and glycoproteins transport for cell plasma membrane and wall edification. In Ulva lactuca in which growth mostly takes place in only five months, the amount of clathrin decreased as a function of plant growth stage. This is in agreement with an involvement of CV in the intracellular traffic of the young tissue with an active metabolism, as further suggested.

Related to the biochemical composition of the whole algae, it is worth noting the important differences in the protein content of the different species: from 40% of dry weight for Porphyra sp. to 20% for Laminaria. Compared to L. digitata, the total amount of protein and carbohydrate measured in U. lactuca was higher and the lipid content lower. In both Laminaria digitata and Ulva lactuca, the lipids identified were: PE, PC, PI, MGDG, and DGDG. These two types of lipids are characteristic of plants and very interesting for their content of polyunsaturated fatty acids.

Analysis of sugar content by gas chromatography revealed the presence, in both Ulva lactuca and Laminaria digitata, of GalNac, GlcNac, galactose, mannose, fucose, glucose and xylose.

From these data on two species of marine algae we can propose a programme of algae utilization in two domains: (i) as a source of protein in human and animal food and (ii) as a source of drug and of drug carrier.

Some species of marine algae like Porphyra and Undaria are very rich in protein, and extraction of these proteins by industrial means will be developed in relation with processing plants like France Luzerne who are interested in this programme. The processes for extracting concentrated purified proteins would be similar to those used for higher plant leaf proteins. To make the protein extraction from some species of algae economically valuable, a preliminary step in the processing should be the extraction of the phycocolloids agar, carrageenan or alginate. A method of extraction allowing alginate recovery from Laminaria digitata without destroying the plant protoplast has been developed and could be used for other species.

On the other hand fundamental research should be continued on genetic and molecular biology of algae. It could be highly profitable for countries producing algae to be able to substitute soyabean protein, which dominates the protein field in food, with the proteins from this source. The characteristics of soyabean protein, i.e. hydration, absorption and texture, should be as far as possible found in the proteins from algae and this might be possible by genetic manipulations of the algal plants.

Finally our knowledge on the composition and function of coated vesicles in algae as well as in higher plants and in animal cells allows us to propose a program of preparing the organelles from different species of algae cultivated in Asia and utilizing them as natural drug carrier. A list of compounds that could be of medical and pharmaceutical use has been established and, according to our data, these compounds should be naturally concentrated in the carrier vesicles. Furthermore these vesicles by their structure are natural liposomes which could carry targeted drug in the organism and, as such, can be charged with specific drug molecules.

The possibilities of algal utilization has been until now largely underestimated, and not scientifically examined. Our proposal is to consider marine algae as a large source of proteins and of drugs, natural or synthetic, without losing the production of the phycocolloids which have still a large world market.

References

Bomsel, M., de Paillerets, C., Weintraub, H. & Alfsen, A. (1986). Biochim. Biophys. Acta. 859, 15–25.

Berkaloff, C. (1963). J. de Microscopie 2, 213–228.

Pearse, B. M. F. (1976). Proc. Nat. Acad. Sci. U. S. A. 73, 1255–1259.

Pearse, B. M. F. (1980). Trends Biochem. Sci. 5, 131–134.

Brodsky, F. M. (1988). Science 242, 1396–1402.

Fowke, L. C. Griffing L. R. Mersey, B. G. & Tanchak, M. (1985). In: Plant Protoplasts (Fowke, L. C. & Constabel, F. eds), CRC Press.

Robinson, D. G. & Depta, H. (1988). Ann. Rev. Plant Physiol. Plant Mol. Biol. 39, 53–99.

Hawes, C. Coleman, J. Evans, D., & Cole, L. (1989). Cell. Biol. Inter. Reports 13, 119–128.

Cole, L., Coleman, J. O. D., Evans, D. E., Hawes, C. R. & Horsley, D. (1987). Plant Cell Rep. 6, 227–230.

Coleman, J., Evans, D. Hawes, C., Horsley, D. & Cole, L. (1987). J. Cell Science 88, 35–45.

Tanchak, M. A., Griffing, L. R., Mersey, B. G. & Fowke, L. C. (1984). Planta 162, 481–486.

Hillmer, S., Depta, H. & Robinson, D. G. (1986). Eur. Cell Biol. 41, 142–149.

Griffing, L. R. & Fowke, J. C. (1985). Protoplasma 128, 22–30.

O'Neil, R. M. & La Claire, J. W. (1984). Science 225, 331–333.

O'Neil, R. M & La Claire, J. W. (1988). Cytobios 53, 113–125.

Huang, X. H., Bomsel, M., de Paillerets, C., Weintraub, H. & A. Alfsen. (1987) C. R. Acad. Sc. Paris 304, 465–468.

Pesacreta, T. C. & Lucas, W. J. (1984). J. Cell Biol. 98, 1537–1545.

Nandi, P. K., Lippoldt, R. E., Alfsen, A. & Edelhoch, H. (1982). Biochemistry 21, 6434–6440.

Laemmli, U. K. (1970). Nature 227, 680–685.

Peterson, G. L. (1977). Anal. Biochem. 83, 346–356.

Ji Minghou & Shi Sengyao. (1962). Studia Marina Sinica 1, 188–194.

Rouser, G. Fleischer, S. & Yamamoto, A. (1967). Lipids 5, 494–496.

Lepage, M. (1967). Lipids 2, 244–250.

Ames, B.N. & Dubin, D. T. (1960). J. Biol. Chem. 235, 769–775.

Chambers, R. E. & Clamp, J. R. (1971). Biochem. J. 125, 1009–1018.

Woods, J. W., Woodward, M. P. & Roth, R. F. (1978). J. Cell Sci. 30, 87–97.

Huang, X. H. Ph.D. Dissertation. Paris 1988.

Emons, A. M., & Traas, J. A. (1986). Eur. J. Cell Biol., 41, 57–64.

Mersey, B. G., Fowke, L. C., Constabel, F. & Newcomb, E. H. (1982). Exp. Cell Res., 141, 459–463.

Mueller, S. & Branton, D. (1964). J. Cell. Biol., 98, 341–346.

Payne, G. S. & Schekman, R. (1985). Science 230, 1009–1012.

Rosa, A. L. & Maccioni, H. J. F. (1987). Mol.& Cell. Biochem., 77, 63–70.

Wiedenhoeft, R. E., Schmidt, G. W. & Palevitz, B. A. (1988). Plant Physiol., 86, 412–416.

Pearse, B. M. F. (1975). J. Mol. Biol., 97, 93–98.

Keen, J. H., Willingham, M. C. & Pastan, I. H. (1979). Cell 16, 303–312.

Rubenstein, J. L. R., Fine, R. E., Luskey, B. D. & Rothman, J. E. (1981). J. Cell Biol., 89, 357–361.

Lehle, L. (1980). FEBS Lett., 123, 63–66.

Berger, E. G. Buddecke, E., Kamerling, J. P., Kebata, A., Paulson, J. C. & Vliegenhart, J. F. G. (1982). Experientia 38, 1129–1258.

Percival, E. & Mc Dowell, R. H. (1967). In: Chemistry and Enzymology of marine algal polysaccharides. pp. 190–197. Academic press, London and New York.

Paillerets de, C., Bomsel, M., Weintraub, H., Pepin, D. & Alfsen, A. FEBS Lett. 219, 113–118.

Ryser, U. (1979). Protoplasma 98, 223–239.

Nakamura, S., Miki-Hiroshige, H. (1982). J. Ultrastruct. 80, 302–311.

Robertson, J. G. & Lyttleton, P. (1982). N. Z. Sci., 25, 99–101.

Franke, W. W., Kartenbeck, J. & Spring, H. (1976). J. Cell Biol., 71, 196–206.

Van der Valk, P. & Fowke, L. C. (1981). Can. J. Bot., 59, 1307–1313.

SUMMARY OF INTERNATIONAL PRODUCTION AND DEMAND FOR SEAWEED COLLOIDS

DAVID JAMES

Senior Fishery Industry Officer
Fish Utilization and Marketing Service
FAO Rome

Information on production of seaweeds and the quantity of products manufactured from them is difficult to obtain with any level of accuracy. There is a variety of reasons for this, including the failure of governments to collect accurate data, lack of interaction between government and industry, commercial secrecy, and others. Almost everyone would benefit from improved production and trade information. Perhaps the workshop can contribute to an improvement in the accuracy of the statistical data such as that reported in the FAO Yearbook of Fishery Statistics. It should be noted, however, that this is historical data and would need to be supplemented by more precise market information such as could be supplied by INFOFISH.

The following brief review is based on information obtained from discussions with industry, and the assistance of Dr. D.J. McHugh with the tabulated data is gratefully acknowledged. Table 1–3 will be published in a forthcoming review (Worldwide distribution of commercial seaweed resources, J. Appl. Phycology. In press).

Estimates of the 1989 production of phycocolloids are given below.

	Phycocolloid (tons)	Raw Materials (dry weight tons)
Alginate	**29,000**	**170,000**
Carrageenan	**11,500**	**85,000**
Seaweed flour	**9,000**	**56,000**
Agar	**6,700**	**51,000**

The demand for phycocolloids is strong and overall demand is expected to increase by up to 10 percent of the next few years.

Alginate

Demand is strong and 1989 production is estimated at 2,900 t, allowing 8,000 for China which may be an underestimate (of up to 2,000 t). Table 1 shows the sources.

Carrageenan

Production in 1989 was probably about 11,500 t of refined carrageenan but, as it is not traded in the farm, the total together with blending materials was about 17,000 t. The Philippines estimates of seaweed flow production are 9,000+ for the period. Table 2 gives sources of raw material while Tables 4, 5 and 6 give supplementary information and projections for carrageenan growth. Future production of seaweed flour will be influenced by the USFDA ruling to classify it as a permitted food additive.

Following a period of declining demand for carrageenan there is now strong growth, anticipated at over 10 percent a year. Although production can be increased by 10–15 percent in the short term, present manufacturing capacity will be fully utilized. Therefore after 1992 (approx) production will not meet demand. This is reflected in increased raw material prices c.f. Europe from US$ 350/t in 1987 to over US$ 700/t in 1990.

Agar

Over the last few years agar production remained unchanged at between 6,600– 7,000 t/yr. However, due to the strong yen, Japanese production and export have declined while Chile and China have increased production to fill the gap. Raw material production was probably about 51,000 t in 1989 (10% loss 15% yield). Table 3 indicates species and harvesting areas.

Table 1. Seaweeds for alginate production - quantity harvest in dry tons

	Laminaria	Ascophyllum	Other
Argentina			500 - Macrocystis
Australia			4000 - Durvillaea
Canada		7400	
Chile			16500 - Lessonia
			2100-Macrocystis
			750 - Durvillaea
China	50000 - japonica		
France	13000 - digitata	1000	1000 - Fucus
	1000 - hyperborea		
Iceland	250 - digitata	4000	
Ireland	1000 - hyperborea	12000	
Mexico			4000 - Macrocystis
Namibia	20 - schinzii		25 - Ecklonia
Norway	25000 - hyperborea	8500	
Scotland	1000 - hyperborea	3000	
South Africa	1500 - schinzii		3500 - Ecklonia
Spain	2000 - various species		300 - Fucus
USA			10000 - Macrocystis

Table 2. Seaweeds for carrageenan production-quantity harvested in dry tons

	Eucheuma	Chondrus	Gigartina	Iridaea
Argentina			80	
Canada		4900		
Chile			2900	4400
China	300 (gelat)			
Fiji	100 (cot)			
France		800		
Indonesia	8000 (cot) 6500 (spin)			
Kiribati	100 (cot)			
Korea Rep.		150		
Mexico			300	
Morocco			200	
Peru			20	
Philippines	50000 (cot) 1000 (spin)			
Portugal		220	200	
Spain		300	600	

Table 3. Seaweeds for agar production-quantity harvested in dry tons.

	Gelidium	Gracilaria	Other
Argentina		2500	
Australia	10		
Brazil		1400	
Chile	410	6800	
		6020 - cult.	
China	200	2000 - cult.	50 (G)
France	300		
India		600	300 (G)
Indonesia	1400	3450	
Japan	3100		
Korea Rep.	2900	50	
Korea DPR	270		
Madagascar	200		
Mexico	1000		
Morocco	4000	200	
Namibia		1200	
New Zealand			250 (P)
Portugal	2000	120	700 (P)
South Africa	190		
Spain	7100		
Taiwan		1600 - cult.	

(G) is Gelidiella, (P) is Pterocladia.

Table 4. Carrageenan and Seaweed Flour - production, demand and price.

	Actual			Predicted	
	1987	1988	1989	1990	1991
Carrageenan					
World production (tons)		16,000	17,000	20,000	22,000
World demand (tons)			20,000	22,000	25,000
Seaweed Flour					
World production (tons)		5,800	6,300	7,000	7,500
World demand (tons)		5,800	6,300	7,000	7,500
Price, US$ (per ton)		3,000	3,200	3,400	3,600

Table 5. Eucheuma cottonii - production, demand and price.

	Actual			Predicted	
	1987	1988	1989	1990	1991
Production (tons)					
Philippines	40,000	50,000	50,000	55,000	60,000
Indonesia	5,000	5,000	8,000	12,000	15,000
Other	250	250	350	500	700
World Production (tons)	45,250	55,250	58,350	67,500	75,700
World Demand (tons)	46,000	60,000	70,000	80,000	90,000
Price, US$:					
c.f. Europe	380	620	720	800	800
c.f. USA	440	680	780	870	870

Table 6. Eucheuma spinosum - production, demand and price.

	Actual			Predicted	
	1987	1988	1989	1990	1991
Production (tons)					
Philippines	2,500	1,600	1,000	1,500	2,000
Indonesia	4,000	5,500	6,500	8,500	10,000
Other	50	50	100	150	200
World Production (tons)	6,550	7,150	7,600	10,150	12,200
World Demand (tons)	6,600	7,500	7,500	10,000	12,000
Price, US$:					
c.f. Europe	390	400	600	700	800
c.f. USA	450	460	660	770	870

Table 7. Minimum daily wage for various countries.

Country	US$
Fiji	6
Kiribati	4
Palau	10
Tonga	5
Tuvalu	3
Malaysia	5
Philippines	2
Indonesia	1

PRODUCTION, MARKETING AND TRADE OF SEAWEEDS

NIRMALA RICHARDS - RAJADURAI

Technical Officer, Technical Advisory Division
INFOFISH, Kuala Lumpur, Malaysia

Abstract

World production of seaweed was approximately 4 million MT in 1988, with production levels similar for the last 5 years. The Asia-Pacific produced 80% of this total and exported an estimated US$ 250 million in seaweeds and seaweed products.

The seaweed industry is worth US$ 1 billion. While agarophytes are in good demand with values increasing, carrageenophytes and alginate-bearing seaweeds have a tendency towards oversupply. World seaweed demand has grown at about 10% annually.

Contrary to seaweed production, 90% of the seaweed colloid industry is concentrated in the developed West followed by Japan and the Republic of Korea. Demand for phycocolloids has grown between 10–30% per year.

Some 400 000 MT (product weight) of edible seaweeds including, *Porphyra, Laminaria, Hizikia* and *Undaria* are mainly produced, consumed and traded amongst Japan, Korea and China. An emerging market is the USA.

1. Introduction

For centuries, various seaweeds have been utilized throughout the world of which edible species were the earliest. Development of their uses were favored by their ready availability and proximity to centres of human settlement, characteristically coastal areas. With human development and discoveries, other species were found to yield medicinal, pharmaceutical, cosmetic, industrial and agricultural use.

The principal use of seaweeds in general is directly as human foods. The other main use of seaweeds is for the extraction of colloids.

The overall world consumption (MT/dry weight) are as follows :

Food for direct consumption	:	400 000 MT
Seaweed colloids	:	50 000 MT

The most dynamic sector of the industry is that manufacturing seaweed colloids for a variety of commercial applications which range from air fresheners, textiles, pharmaceuticals, processed foods, medias for medical, industrial, microbiological and horticulture applications in tissue and cell culture.

While the seaweed industry traditionally relied on the exploitation of naturally growing beds, presently advances in seaweed culture meet demands and replace depleted stocks. For example, Chile is the world's largest producer and exporter of *Gracilaria* and *Gracilaria*-derived agar. In the last decade, its supply to Japan has less than halved (7851 MT in 1980 to 2728 MT in 1987). It is believed that much of the natural resource has been depleted, and Chile now actively practices mariculture (Pers. Comm. S. van Eys, INFOPESCA, July 1990).

The production, utilization and international trade of commercial seaweeds and their products have been reviewed in the past by Naylor (1977), the International Trade Centre UNCTAD/GATT(1981), McHugh and Lanier (1983) and in separate reviews in 1987 on Agars (Armisen & Galatas), Carrageenans (Stanley) and Alginates (McHugh) compiled in the FAO Fish. Tech. Paper 288 - 'Production and Utilization of Products from Commercial Seaweeds' (McHugh, 1987).

2. World Production of Seaweeds

Seaweeds and aquatic plants are broadly classified into brown, red, green seaweeds and miscellaneous plants. Of these red and brown seaweed are the most important commercially.

In 1988, the total seaweed production was about 4 million MT (wet weight) (FAO, 1990). The main groups were produced in the following order: brown seaweeds (2.5 million MT, 66.5%), red seaweeds (1.25 million MT, 33%) and green seaweeds (15 000 MT, 0.4%).

While traditionally seaweed was collected from the wild, virtually all brown seaweed, 63% of red seaweed and 68% of green seaweed are now maricultured (Table 4). The main species maricultured are *Laminaria japonicus, (Phaeophyceae), Undaria pinnatifida*, (brown seaweeds), *Eucheuma spp, Gracilaria spp, Porphyra tenera,* (red seaweeds) and *Monostroma nitidum* (green seaweed).

World seaweed production by country and seaweed type are shown in Tables 1,2,3 & 4. Leading producers of seaweed in 1988 were China, Japan, Republic of Korea followed by the Philippines, USSR, Norway and Chile (See Fig. 1 & Tables 1,2,3,4 and 5 (i, ii, iii). The Asia-Pacific region, accounts for the production of some 3 million MT (80%) of the world's total production mainly for the colloid industry (Table 6) while seaweed for human consumption is mainly produced in the 3 major consuming countries - China, Japan, Republic of Korea and Taiwan.

Note:

Figures used in this paper are FAO estimates and have been questioned by some authors in the past. Production is usually given as wet weight while product is quoted in dry weight. Export statistics for some countries such as China and Vietnam could not be obtained at time of preparation, to accurately evaluate seaweed trade figures from the Asia-Pacific.

3. International Markets, Industry and Trade.

World seaweed demand grows at about 10% per year. World trade in seaweed and seaweed products was valued at US$ 50 million in 1970, and five times that in 1980 (ITC/UNCTAD/GATT 1981). In 1988, an estimated US$ 250 million worth of seaweed and seaweed products were exported from the Asia-Pacific region alone.

The international demand for phycocolloids (agar, alginates, carrageenan and furcellaran) has grown much more rapidly. The world seaweed colloid market was estimated at US$ 1 billion and to have grown between 10% to 30% per year during the 1980s (Bung-Orn, 1989).

While world supply of seaweeds is mainly from developing countries, the seaweed colloid manufacturing industry is concentrated in a few developed nations: Denmark, France, Japan, Norway, Spain, the United Kingdom and the United States. Colloid manufacture is slowly developing in a few seaweed producing countries in Asia.

Potential producers from developing countries wishing to enter the seaweed and seaweed colloid trade will face very stiff competition from the established producers. Often, since colloids are made up specifically and marketed with technical support for its use, market preference and confidence in a particular performing brand or grade of colloid is difficult to dislodge despite their higher price (INFOFISH, 1983). Similarly, since the quantity and quality of derivatives from seaweeds vary and are characteristic for a particular geographical area or season, market acceptance of seaweeds from new sources may be difficult and prices offered somewhat low.

Competitors to phycocolloids in some applications and uses come from plant gums and cellulose derivatives. While competing colloids are usually cheaper, established performance of seaweed colloids in certain applications give it a firm foothold in the market.

3.1 Agars & Agarophytes

a. World Production

Total world production of agar was estimated at 7 000–10 000 MT half of it originating in Japan and Rep. of Korea (Globefish, 1988). The major producing countries are Japan, Spain, Chile and Rep. of Korea. Many leading producers of agar export most of their production (Tables 7 & 8). Emerging producers in the Asia-Pacific are Indonesia, the Philippines and Thailand.

The world agar industry uses the following seaweeds: *Gracilaria* -Chile, Argentina, S. Africa, Japan, Brazil, Peru, Indonesia, Philippines, People's Republic of China, Taiwan Province, India and Sri Lanka.

Gelidium	-	Spain, Portugal, Morocco, Japan, Korea, Mexico, France, USA, People's Republic of China, Chile and S. Africa (until 1960), the major and preferred source of agar)
Pterocladia	-	Portugal (Azores), New Zealand.
Gelidiella	-	Egypt, Madagascar, India etc.

(Source : Armisen & Galatas, 1987).

b. The Agar Industry, Market and Trade :

The agar industry today probably represents a market value well above US$ 200 million (Bung-Orn, 1989). Agarophytes are higher priced than other colloid-bearing seaweeds.

International trade in agar is active and values are increasing (Fig.3) An estimated 10 000 MT of raw agar and 3 500 MT of final product enter international trade each year. The raw material goes principally to Japan, which is also the main exporter of agar final product (Globefish, 1988).

In 1987 Japan imported 9 205 MT of Agarophytes. Japanese imports of agar-bearing *Gelidiaceae* increased from less than 700 MT in 1980 to 2 100 MT in 1987, though this is less than the average annual import of 8 600 MT of *Gracilaria* during the same period. Japan exported about 450 MT of agar product, 40% of this to countries of South and South East Asia.

Japan is the main agar consuming country (about 2 000 MT a year), almost all coming from domestic production. Since Japan produces, exports and imports a large quantity of the agar, it is used as an index for world production (Armisen & Galatas, 1987).

The USA another major consumer (1 000 MT per year), obtains more than 80% from imports, main suppliers being Chile, Morocco and Spain, and more recently the Philippines. In 1987, the Philippines succeeded in entering the agar market by shipping 300 MT of agar to the USA (Globefish, 1988). In 1990, the Philippines is expected to export Agarophytes to China, presently facing short supply of Porphyra from which their agar is derived.

The demand for agar in the EEC is approximately 1300 MT per year (Globefish, 1988).

Demand exists in newly developed and developing countries for food-grade and bacteriological agar. Thailand, Indonesia, Singapore and Malaysia import about 200 MT each per year. Main suppliers to the region are Republic of Korea and Japan, while Chile recently established a foot-hold in this market (Globefish, 1988). Thailand, Malaysia, Indonesia and India have small domestic production of agar, whilst exporting insignificant quantities (Tables 9 & 10).

Agar is marketed pure. High-grade agar is white, while yellow is allowed for lower grades. Apart from seaweed powder and dried/treated Agarophytes, other product forms are pill, strip, flake and powdered agar. Prices for dried seaweed or alkali-treated seaweed (colagar) vary depending on the agar quantity and quality. Prices are often quoted after extraction has been completed by the importer or end-user. Prices depend on gel strength, specifications and applications.

Marketing of industrial grade agar is generally through international trading companies dealing with food additives. Bacteriological agar is most expensive and represents 4-5% of total agar sales. With increasing demand and legislation for wholesome foods by consumers and major food importing countries, the demand for bacteriological agar will continue to grow. Main suppliers are the USA and the UK. Agarose, an agar-derivative with biochemical applications is the highest priced seaweed product, taking 0.2% of the market (Armisen & Galatas 1987).

Decline in agarophyte prices in world markets can only be anticipated with increased production of raw material. Meanwhile, the demand for agar remains strong as evidenced by continuing high prices and ease with which exporting countries such as Japan, People's Republic of China and Republic of Korea dispose of their product. Agar appears to have priced itself out of certain markets with resultant takeover by competitive colloids. For instance, carrageenan replaced agar in canned meats.

Market potential for additional volumes of agarophytes from mariculture in the Asia-Pacific is encouraging. Mariculture of *Gracilaria* should be linked with the manufacture of agar in the region rather than the export of dried weeds. This would benefit the national economies involved, while expensive agar imports are also being replaced by domestic production (McHugh & Lanier, 1983). China, India, Thailand and Indonesia have already developed processes for small-scale agar manufacture. China has about 100 small agar factories producing 200– 300 MT annually. Prices fluctuate greatly between RMB55 000/MT (1988) to RMB105 000/MT (1990) (Pers. Comm., Lian Peizhi, Xiamen Fisheries College, Aug, 1990). In Indonesia, *Gracilaria* is maricultured in South Sulawesi. Plans are underway for setting up an agar-processing factory which will utilize 50–100 MT raw material per month (Hussain, 1989). Much needs to be done to bring the regional industry up to par with international standards and requirements. Full-scale development will have to depend very much on the regional and worldwide market, with perhaps joint-ventures with established colloid producers.

3.2 Carrageenan and Carrageenophytes:

a. World Production

World production of carrageenophytes was estimated at 43 500 MT in 1984 (Stanley, Marine Colloids, 1987) and 65 000 MT in 1989 (Pers comm., Hans Porse, Copenhagen Pectin, July 1990), a growth of over 20 000 MT raw material in 5 years.

In 1984, principal producers were the Philippines (*Eucheuma*), Chile (*Iridaea*), Canada (*Chondrus crispus*), Indonesia (*Eucheuma*), Spain, France, Portugal, Morocco and others (*Gigartina acicularies* and *G. pistillate*) (Table 11). A potential producer is China, (*Eucheuma spp.*).

E. cottonii and *E. spinosum* are now heavily utilized by carrageenan producers and are commercially maricultured in the Philippines and Indonesia. They are turned into both dried seaweed and semi-refined carrageenan.

The demand for *Eucheuma spp.* is estimated to be 50 000 MT/year. The growth of production by these major producers has done much to increase and stabilize the supply of carrageenophytes. In the future, it is expected that production will outpace demand expansion.

In the Philippines, two decades of seaweed culture has brought about improvement in culture practices and yields. Since 1979, production grew from 100 000 MT to 277 000 MT in 1989. It declined by 27% from 1980 (114 000 MT) to 1981 (83 000 MT), and again from 1985 (182 000 MT) to 1986 (169 000 MT). The biggest increase of 36% was recorded from 1986 to 1987 (Anon, 1990(3)).

In an attempt to protect the seaweed production industry, the government of the Philippines recently banned the export of seedlings to neighboring Indonesia.

In 1970, the Philippines exported 318 MT of seaweed then valued at US$ 0.092 million. In 1989 the estimate was 50 000 MT (a 150-fold increase) valued at US$ 40 million. Exports grew at an average of 10% per annum in the last decade, and are projected to reach US$ 50 million in 1990 (Anon(2) 1990).

In 1978–1979, the annual yield of dry weight seaweed was 6 272 kg/ha/yr, 10 years later it was 36,036 kg/ha/yr (Padilla & Lampe, 1989). Figs. 3 and 4 illustrate the increase in seaweed production and hence export by the Philippines. The overall average dry weight production in the Philippines is 12 MT/ha/yr (McHugh & Philipson, 1988).

In parts of the Philippines, buying stations have been located among several farms. Multinational companies have designed strategies for wide acceptance of seaweed culture among fishermen such as contract-farming schemes, provision of farm inputs, and marketing of produce. Non-price competition is practiced amongst the few buyers who control the market (Padilla & Lampe, 1989). In other areas, farmers may be disorganized, and marketing individualistic, rushing to sell on demand resulting in low quality and production yields, and therefore poorer profits. (Pers. Comm., Trono, 1989).

Indonesian seaweed production is growing. The average yield is 50–100 MT/ha/yr. In 1988, annual production was approximately 3 000–4 000 MT (*E. cottonii*) and 4 500–5 000 MT (*E. spinosum*) (McHugh & Philipson, 1988) (Fig. 5). In the '60s, Indonesia supplied 1/4 to 1/2 of world *Eucheuma*, mainly *E. spinosum* from wild crop. With poor supplies, cultured production switched to the Philippines in the 1970s. *E. spinosum* culture was then introduced to Bali in 1978. When prices fell in 1979, minimal production continued at the rate of 10 MT/yr until 1983. In 1984, productivity rose to 600 MT/yr and by 1986, 200 MT/mth! Manufacturers of carrageenan could not absorb this *E. spinosum*. Hong Kong buyers stepped in and currently import 400 MT/mth. Marine Colloids of Indonesia also switched to the development of *E. cottonii* production.

b. The Carrageenan Industry

About 12 000–15 000 MT of carrageenan are utilized by the industry annually. (Stanley, 1987). In 1989, 13 000 MT was utilized. (Pers Comm., Copenhagen Pectin, July 1990).

Ninety percent of the world carrageenan industry lies in developed countries. Marine Colloids (a subsidiary of MC Corporation) is the sole domestic producer of carrageenan in the USA and its production in 1981 represented nearly 40% of total world production. In Denmark, two companies Litex A/S and Genu (A/S Kobenhavns Pektinfabrik) together manufactured 30%, while France Satia, the world's second largest producer manufactured a further 25% (McHugh & Philipson, 1988). The leading carrageenan producer in Asia is the Republic of Korea.

Domestic processing of *E. cottonii* in the Philippines began in 1878. Philippine processing of *E. spinosum* began in 1983 and reached 800 MT in 1986. In 1987, 23 000 MT was processed locally.

Shemberg Marketing Corporation, Philippines, associated with Hydralco GmbH, Germany was the first and until 1988 the only manufacturer of refined carrageenan in the Philippines. Other principal Philippines processors are MCPI Corporation (linked with Marine Colloids of the US), Genu Products, Philippines (linked with Genu, Denmark) and Marcel Trading Company, which owns a carrageenan refinery in Taiwan.

Now there are two carrageenan producers in the Republic of Korea and three principal ones in Japan. The main source of raw material is *Eucheuma* from the Philippines, while Republic of Korea also buys from the Philippines. Carrageenan was not produced in China till 1985. Now, in China, there are two carrageenan factories in Hainan, one using Philippines seaweeds and another locally produced *Eucheuma*. Their output and uses are still quite limited. In Indonesia, a joint-venture with a Japanese company resulted in a 40 MT factory for semi-refined carrageenan (McHugh & Philipson, 1988).

c. The carrageenan and carrageenophyte market

Carrageenan enjoys a good market due to growing demand. The seaweed output market has about five major buyers. Moderate excess of production over sales exists (Stanley, 1987). Market demand for *E. spinosum* yielding iota-carrageenan is stronger than that for *E. cottonii* yielding kappa carrageenan. *E. cottonii* is facing an oversupply situation through significant increases in mariculture (Stanley, 1987).

In July 1990, the United States lifted its ban on Philippine natural grade (PNG) carrageenan for use as food additive. The product had been banned at the instigation of a US competitor in 1985. This opens a market of up to US$ 40 million for the local seaweed industry (New Straits Times, 26 July 1990, Malaysia).

Burrows, FMC Corp (Anon, 1990) recently reported the Asia-Pacific market as growing rapidly. According to him, Konjac flour a newly introduced carrageenan-based hydrocolloid will require substantial raw material from the Far East.

Carrageenan's potential use as binders in aquaculture feeds - a growing industry itself - could well serve as a boom to the industry and its market.

Distribution of carrageenan sales by end-use and region are depicted in Table 12. Note that the different types of carrageenan obtained has a very significant effect on segmenting the market.

China is especially interested in the use of carrageenan for improving food products. While *Eucheuma* production is underway in Hainan, China could be a potential large volume market.

Lower priced 'semi-refined' carrageenan has almost totally replaced 'refined' carrageenan in several applications. The market for normal grade 'refined' carrageenan is growing slowly, about 5 percent per annum. It is utilized in many prepacked foods in developed countries. If new application for the product are found, the market could well expand, otherwise in any new production 'semi-refined' carrageenan might simply replace 'refined' carrageenan in established uses, resulting in more limited sales potential (McHugh & Lanier, 1983).

d. Carrageenan and Carrageenophyte Prices

Carrageenophyte prices are very sensitive to supply fluctuation, especially for *E. spinosum* (Fig.6). Prices are cyclical; as demand increases, farmers move into production creating oversupply, which forces a drastic drop in prices. Production decreases and moves the prices up again. 1988 prices were about half the 1980 price (Globefish, 1988).

In the Philippines, ex-farm prices for *Eucheuma* of Pesos 1.42/kg (US$ 0.06/kg) in 1972, increased to Pesos 6.17/kg (US$ 0.26/kg) in 1988. Prices for *Eucheuma* seaweeds paid by major buyers in Cebu have moved in opposite trends to the above, so that profit to traders is smaller while farmers receive better prices for their produce. For comparison purposes, ex-farm Indonesia was US$ 0.11–0.20/kg), Philippines - US$ 0.20–0.23/kg, Fiji - US$ 0.28/kg (McHugh & Philipson, 1988).

In 1978 it cost Pesos 0.56 (US$ 0.02) to raise 1 kg of seaweed. In 1989 it cost Pesos 1 (US$ 0.04 in 1978 Pesos), so that costs for production have increased. Indicative prices for raw *E. spinosum* and *E. cottonii* (35% moisture) for 1987 are presented below:

July 1987 Indonesia US$/MT (FOB). USA US$/MT (CIF). Europe US$/MT (CIF)

E. cottonii	265	455	355
E. spinosum	242	432	332

(Source : McHugh & Philipson, 1988).

The Philippine product fetches a similar price. The wide disparity between US and European cif prices for *Eucheuma* is mainly due to the cost of freight. The Pacific Islands, in particular Fiji produced *Eucheuma* for Coast Biologicals in New Zealand. Since that market closed its doors, Fiji found it uneconomical to ship seaweed to US and European buyers, given prices offered by other producers worldwide.

With *Eucheuma* supply high, prices are not expected to increase.

3.3 Alginates

a. World Algin and Alginate-seaweed Production

Alginates represent the most important seaweed colloid product in terms of volume. Production averages 22 000–25 000 MT/yr. Alginates production is concentrated in a few companies in the USA, UK, Norway and France. It is expected that demand for alginates will reach 50 000 MT/yr by 1995 (Globefish, 1988).

Alginates are used in food (30 percent of total production) textiles (50 percent of production) and other industries (Globefish, 1988). Alginate is derived from most brown seaweed growing in cold waters. Harvest takes place in processing countries with alginate producers arranging their own seaweed collection. The property of alginate derived varies with species and therefore, influences the choice of seaweed harvested. The main commercial sources are *Ascophyllum, Laminaria* and *Macrocystis*. Other species used are *Sargassum, Durvillaea, Ecklonia, Lessonia* and *Turbinaria*.

Laminaria is produced in China, Japan and Korea and is a major and popular food seaweed. In Japan and Korea the high demand for edible *Laminaria* and resultant higher price forces importation of brown seaweeds for alginate production. Chinese use cultured *Laminaria* for alginate production. Production is increasing in China and reported to be 7 000 – 8 000 MT/yr in 1987 (McHugh, 1987). Owing to its shortage, between 1988 and 1990, some sargassum is also being used. There are 32 alginate processing plants in China. Production and prices for Chinese alginate are depicted in Table 16.

In North America, Kelco Incorporated turns 50 000 MT of *Macrocystis* into US$ 100 million of algins (Anon(3), 1990).

b. Alginate Prices

Prices for dried seaweed depend on moisture and alginate content, and can show considerable variation from year to year. FOB prices can vary from US$ 150/MT (*Lessonia*, Chile) to US$ 500–700 (*L. japonica,* China) (McHugh, 1987). On the international market, Chinese alginate is much cheaper than alginate of other countries thus meeting with strong opposition from US manufacturers. However on the domestic market, the price is higher. Prices have fluctuated from RMB38 000/MT to RMB32 000/MT (July, 1990) (Pers. Comm. Lian Peizhi, Aug, 1990).

Prices for alginates depending on their uses are as follows :

Sodium alginate-pharmaceutical (US$ 13–15.50/kg),
Food grade (US$ 6.50–11.00/kg), and
Technical grade (US$ 5.50–7.50/kg).

(Source : McHugh, 1987).

c. Alginate Trade

International trade in alginate products is shifting with expansion of the textile industry in developing countries leading to strong demand. Approximately 8 000–10 000 MT are used in the Asia-Pacific, most of it imported. About 12 000–15 000 MT of alginates stay in development countries (Globefish, 1988). Japan relies on imports for its own alginate production of 1 500 MT/yr (Globefish, 1988).

Buyers generally fall into two groups, a few large volume buyers who are mainly specialty gum companies, and a larger group of small-volume users who require and receive technical support service from suppliers as part of the package.

The alginate market is expected to remain stable (Globefish, 1988). Supplies are plentiful with an indication towards oversupply and the possibilities of alginate substitutes decreasing demand.

Potential for developing Asian producers and exporters can only exist where a domestic market for both the seaweed and the resulting alginate exists. There is a possibility of increased usage of alginate in India by the textile printing industry, but the domestic source of alginate-*Sargassum* species yields a poor quality alginate for this use. The importation of better species could help the problem. The Philippines is interested in alginate production from *Sargassum* but has little domestic market for it. The Republic of Korea has suitable seaweeds but imports alginate in appreciable quantities.

3.4 Edible Seaweeds

A large market for edible seaweeds exists especially in the Far East. Main consumers are Japan, China and Rep. of Korea with a total annual consumption of 400,000 MT product weight or 2 million MT wet weight each year. The bulk of the edible seaweed trade is centred around these 3 countries. The main product forms are nori (*Porphyra*), kombu (*Laminaria*), hijiki (*Hizikia*) and wakame (*Undaria*). Practically all edible seaweeds can be and are produced by mariculture, by natural extension of the use of mariculture for industrial use. Other Asians (mainly ethnic Chinese) also consume fresh or dried seaweed (Table 19).

The bulk of the edible seaweed trade is centred around the 3 major producers-China, Japan and Republic of Korea (Tables 13–18).

The trade pattern shows Japan as main importer and Republic of Korea biggest exporter. Much of Korea Rep's production is exported to Japan, where some US$ 90 million is spent importing edible seaweeds.

a. Japan

In Japan, Kombu (*Laminaria*), Nori (*Porphyra*), Hijiki (*Hizikia*) are all marketed in dried form, while Wakame (*Undaria*) is marketed in boiled and salted forms.

Some 120,000 MT of finished product (about 700,000 MT of seaweed) (Globefish, 1988) are reported to be consumed in Japan annually. Nori accounts for about 45 percent of Japanese seaweed consumption, all of which is cultured. It is a US$ 1.5 billion dollar business in Japan (Anon, 1990(3)). Domestic production now satisfies internal demand. Wakame accounts for ⅓ of Japanese seaweed consumption. Half of this is derived from imports, with Republic of Korea exporting 26,000 MT and China, 5,500 MT in 1987.

Wakame was oversupplied 1988. Japan produces some 100 000 MT annually and imports another 30 000MT from Rep. of Korea and China.

Dried Nori has long been oversupplied. In 1988 production was 11.4 billion sheets (38.5 percent higher than the previous year) with no imports.

Demand for Kombu is strong because it is considered health food. Domestic production in 1988 was 132 000 MT from wild harvest and 59 000 MT cultured, a 10.5% increase. Approximately 1 900 MT of kombu are exported from Japan annually.

Japan has a substantial export trade in edible seaweeds amounting to 34 000 MT valued at approximately US$ 60 million.

b. Rep. of Korea

Korea Rep harvests some 450 000 MT seaweed each year, mostly wakame and about 100 000 MT nori. The Republic of Korea consumes 400,000 MT of seaweed (120,000 MT product weight) with the highest per caput seaweed consumption. Wakame constitutes 75% of intake, while Nori accounts for the remainder.

In 1988 Hijiki production was 36 852 MT, 11.2% more than the previous year, and Wakame 288 368 MT, 1.3% less.

c. China

About 1 million MT wet weight of seaweed (150 000 MT product weight) is produced annually, kombu (800 000 MT), nori (120 000MT) and wakame (12 000MT). Most of China's production is consumed within the country.

d. Taiwan

Imports of edible seaweeds was 3 665 MT, double the previous year perhaps due to the popularization of Japanese cuisine. Supplies were 3 515 MT from Japan, (94.7% increase) followed by Rep Korea (87 MT).

e. USA

The USA is the fastest-growing nori market in the world. Owing to popularization of Japanese restaurants and immigration of Asians, demand for *Nori* is increasing. The size of this latest market is US$ 10 million, increasing by 10 percent every year. Major suppliers are Japan, Rep Korea, China and Taiwan. In Washington State, Nori is being cultured on a small scale.

f. The ASEAN

Principal seaweed genera of economic potential in the ASEAN region are depicted in Table 19. While the commercially important species are traded, consumption of the edible varieties generally do not enter commercial channels. These are consumed fresh in salads or preserved form (by salting/drying) and resoaked in water prior to use or used in desserts.

4. FUTURE DEVELOPMENT

4.1 New Market

China is the world's leading seaweed producer. It uses seaweeds primarily for domestic markets and human consumption. Lately, China is more interested in the use of Carrageenan for improving food product, and so could be a potential for a large volume market. They also culture about 5000 MT of *Gracilaria* per annum around Hainan. With promising results, China expects a substantial development of *Gracilaria* culture to meet the increased demand for agar.

4.2 Aquaculture Feeds

Work is proceeding in developing the use of Carrageenan as a binder in aquaculture feeds. It has been estimated that by the year 2000, Asia alone will probably need 1.1 million MT of shrimp feed (New and Wijkstrom, 1990). Given a 1–3% requirement for a feed binder, the estimated utilization of colloid binders which may originate from seaweeds is 33 000 MT ! Broadly estimating, this would require five times the quantity of dried seaweeds or another 165 000 MT of seaweed from which gels for binders may be derived annually. On an experimental level, a feed technologist has boiled *Eucheuma* to extract the colloid, mixed the resulting colloid proportionally in a molasses mixer and incorporated it into fish feeds. It is claimed to work well as a binder (Pers. Comm. Kuan Foo Seong, Amerisia Sdn. Bhd., 1990).

4.3 Culture Methods/Application in Biotechnology

Rapid spray cultivation in fine mists of seawater as an alternative growth system to natural harvesting and yields of up to 140 MT (dry weight) per year is economically bringing seaweed into contention as sources of many new chemicals, particularly fine chemicals such as enzymes.

Thus practical use for seaweeds, especially now, in the field of biotechnology are more diversified than have been hitherto anticipated. Now available are the possibilities of enzymatic post-harvest modification of alginic acid, extraction and purification of non-protein amino acids with bio-inhibitory effects and the use of seaweed biomass as a sole nutrient source to heterotrophic microbes of mineral biodegradation (Madgwick, 1990).

5. RECOMMENDATIONS

5.1. Develop Market Intelligence and Strategies

In the seaweed industry, although end-users are many, international buyers are relatively few and large processing concerns. Technical developments for the seaweed producing industry have to be closely linked with adequate marketing arrangements and a study of the supply/demand picture. Well designed distribution and marketing programmes will ensure commercial viability and resultant growth.

Find means applicable in each country to simplify distribution, increase market acceptability and raise returns to growers.

Constant evaluation and monitoring of existing markets should be carried out by potential seaweed exporting countries to evaluate and control production and therefore, keep tab on price fluctuations.

Countries culturing seaweed should exercise caution and control in the number of land ceases granted to prevent supply exceeding demand with resultant slump in prices and therefore losses to the farmers.

Special attention should be given to an appropriate form of organization for selling seaweeds and supplying initial credits facilities to farmers/fisherfolk.

A distinction between domestic and international market orientation needs to be made. The two markets bring to bear different economic conditions and marketing structure that influence prices and hence profits to seaweed collections and farmers. Outlets are not a matter of producers' choice in that potential markets are determined by characteristics of and available uses for fresh and processed seaweeds.

Localize the colloid industry where possible especially agar and now refined carrageenan. Domesticate the industry with imported technology. Find end-uses within the region. Domestic markets should be expanded to reduce overdependence on foreign markets and utilize domestic production.

5.2 Developing and Improving Technology

Past experiences indicate that quality control in harvesting, cleaning, sorting, washing, drying and semi-processing have to be given greater attention.

Priorities should be given to selection of species with higher growth rates, higher yield of colloid and better quality.

Research is required to develop fast growing, high yielding varieties through biotechnology.

Development of polyculture - seaweed with fish or shrimp or *Gracilaria* with abalone farming should be considered.

Conserve Natural Stock. Encourage cutting or pruning when harvesting from natural seaweed beds so as to preserve the natural resources.

References

Anon. 1990(1). 'FMC Marine Colloids Open New Office in Singapore.' Asia-Pacific Food Industry, March, 1990; p 62.

Anon. 1990(2). 'Seaweed Updates', Vol. 1 No 3, May, 1990. Dept. of Agri./Board of Investment, Philippines.

Anon. 1990(3). 'Sea Vegetables', Seafood Leader. (March/Apr, 1990): 283–297: 12p.

Armisen & Galaktas. 1978. 'Production, Properties and Uses of Agar' in McHugh D.J. (ed). 'Production and Utilization of Products from Commercial Seaweeds'. FAO Fish. Tech. Pap., (288): p 1–57.

Bung-Orn, S. 1989. 'Opening Address' - A Seminar on *Gracilaria* - Production and Utilization in the Bay of Bengal, Oct., 1989, Songkla, Thailand.

Coppen, J.J.W. 1989. 'Production of Agar from Seaweeds, with special reference to India'. Paper presented at Bay of Bengal Programme 'Seminar on *Gracilaria* Production and Utilization in the Bay Bengal' 23–27 Oct, 1989, Songkhla, Thailand.

FAO. 1989. 'Aquaculture Production (1984–1987)' FAO, Fisheries Circular No. 815 Rev. 1, Rome: 130p

FAO. 1990. Yearbook of Fishery Statistics: Catches & Landings, Vol. 66, 1988. FAO Fisheries Series No. 34, FAO Statistics Series No. 92.

Globefish, FAO. 1988. 'Seaweed - The Least Known of Marine Based Industries - Special Feature'. Globefish Highlights No. 3/88.

Hussain, S.A. 1989. 'The Development of Commercial *Gracilaria* farming in Sulawesi, Indonesia.' BOBP Seminar on *Gracilaria*. Production and Utilization, Oct. 1989, Songkla, Thailand: 10p

INFOFISH. 1983. 'Seaweeds - Products and Markets'. INFOFISH Marketing Digest No. 4/83: p 23–26.

ITC, UNCTAD/GATT. 1981. 'Pilot Survey of the World Seaweed Industry and Trade', Geneva, 1981: 111

Jahara, J. & Phang, S.M. 1989. 'Seaweed Marketing and Agar Utilisating Industries in Malaysia'. Paper Presented at the Bay of Bengal Programme 'Seminar on Gracilaria Production and Utilisation in the Bay of Bengal' 23–27 Oct., 1989: 68p.

Jingwen, T. 1987. 'Status and Trends of Seafarming in China'. Report on the First National Coordinators Meeting on Regional Seafarming and Demostration Project, Bangkok, Thailand: p15–18.

Madgwick, J. 1990. 'Untapped Source of Chemicals and Food' Asia-Pacific Food Industry, March 1990: p 22.

McHugh D.G. & Lanier, B.V. 1983. 'The World Seaweed Industry and Trade: Developing Asian Producers and Prospects for Greater Participation'. ADB/FAO/INFOFISH Market Studies Vol. 6: 30p.

McHugh, D.J. 1987. 'Production, Properties and Uses of Alginates. In McHugh, D.J. (ed) Production and Utilization of Products from Commercial Seaweeds, FAO Fisheries Technical Paper (288): p58–115.

McHugh, D. and Philipson, P., Jan. 1988. 'Post-Harvest Technology and Marketing of Cultured *Eucheuma* Seaweeds, FFA Report 88/2: 19p.

Naylor, J. 1976. 'Production, Trade and Utilization of Seaweeds and Seaweed Products. FAO Fisheries Technical Paper No.159: 73p.

New, Michael B. and Wijkstrom, UN. 1990. 'Feed for Thought' World Aquaculture Vol. 21(1), March 1990: p 17–19, p 22–23.

Padilla, J.E. & Lampe, H.C. 1989. 'The Economics of Seaweed Farming in the Philippines.' NAGA, The ICLARM Quarterly, July 1989: p3–5.

RAPA Publication. 1989/6. 'Marine Fishery Production in the Asia-Pacific Region.'

Stanley, N. 1987. 'Production, Properties and Uses of Carrageenan. In McHugh, D.J. (ed) Production and Utilization of Products from Commercial Seaweeds. FAO Fisheries Technical Paper (288): p117–147.

APPENDICES

A List of Tables

1. World Brown Seaweed Production, 1985–1988
2. World Red Seaweed Production, 1985–1988
3. World Green Seaweed and other Algae Production, 1985–1988
4. Aquaculture Production by Species Groups, 1984–1987
5. Main Seaweed Producing Countries by Seaweed groups (i), (ii) and (iii)
6. Main Seaweed production and producing countries
7A. Agar Production in Different Countries (1984)
7B. Japan: Import of Agarophytes, 1984–1987
8. Major Agar Exporters, 1986, 1987
9. Agar Imports: BOBP countries (tonnes)
10. Agar Exports: BOBP countries (tonnes)
11. Production of Carrageenan Seaweed World Basis in MT
12. Distribution of Carrageenan Sales
13. Japan: Production of Edible Seaweed, 1987–1989 (thousand MT)
14. Japan: Exports/Imports of Seaweed, 1985–1988
15. Statistic on the production of cultured seaweeds in China, 1984–1988
16. Production & Prices of Seaweed in China, 1989–1990
17. Republic of Korea: Annual Production of Seaweed by Species, 1980–1987 (Net Weight in MT)
18. Republic of Korea: Edible Seaweeds Imported/Exported (1985–1987) MT.
19. Principal Seaweed Genera of Economic Potentials in the ASEAN

B List of Figures

1. Main Seaweed Producers (1989)
2. Agar strip (Import Price to Malaysia) (1989)
3. Philippines Production of Seaweed, 1979–1989
4. Philippine Dried Seaweed Exports, 1979–1989
5. Indonesia Seaweed Exports, 1980–1987
6. Average Prices Paid for *E. cottonii* and *E. spinosum* (1978–1986).

Table 1. World Brown seaweed production, 1985–1988. Production by species, fishing areas and countries or areas.

Species	Fishing area	1985(mt)	1986(mt)	1987(mt)	1988(mt)
Brown seaweeds			*Phaeophyceae*		
France	27	67 523	65 103	58 019	103 663
Iceland	27	15 148	10 237	12 215	14 984
Norway	27	133 319	159 328	174 109	172 148
Spain	27	420	1 260	3 249	2 364
USSR	27	18 297	17 699	15 418	20 039
UK Scotland	27	12 763	10 050	7 140	10 698
Area total	**27**	**470 477**	**270 150**	**323 896**	**323 896**
Argentina	41	282	40	2	2
Area total	**41**	**282**	**40**	**2**	**2**
South Africa	47	20 920	21 000	21 000	21 000
Area total	**47**	**20 920**	**21 000**	**21 000**	**21 000**
Australia	57	13 627	12 862	16 248	17 955
Area total	**57**	**13 627**	**12 862**	**16 248**	**17 955**
China	61	1 523 034	1 220 622	1 073 400	1 298 490
Japan	61	306 211	328 573	294 518	309 253
Rep Korea	61	299 932	389 399	339 289	338 805
USSR	61	14 119	23 100	34 181	51 184
Area total	**61**	**2 143 296**	**1 961 694**	**1 741 388**	**1 997 732**
USA	67	-	-	-	-
Area total	**67**	-	-	-	-
Mexico	77	31 380	42 509	38 931	20 077
USA	77	81 239	53 908	80 539	67 429
Area total	**77**	**112 619**	**96 417**	**119 470**	**87 506**
Chile	87	36 033	28 025	33 532	70 673
Area total	**87**	**36 033**	**28 025**	**33 532**	**70 673**
Species total	S	2 574 247	2 384 515	2 201 790	2 518 764
Group total	**S**	**2 574 247**	**2 384 515**	**2 201 790**	**2 518 764**

Source: FAO, 1990.
FAO Yearbook of Fishing Statistics, 1988.

Table 2. World Red Seaweed Production, 1985–1988. Production by species, fishing areas and countries or areas.

Species	Fishing area	1985(mt)	1986(mt)	1987(mt)	1988(mt)
Red seaweeds				*Rhodophyceae*	
Canada	21	22 610	17 240	29 550	17 230
USA	21	-	1 588	-	4 082
Area total	**21**	**22 610**	**18 828**	**29 550**	**21 312**
France	27	2 479	1 943	3 307	2 468
Portugal	27	7 908	5 955	6 349	5 385
Spain	27	4 063	4 754	5 548	5 130
USSR	27	1 329	1 363	1 819	924
Area total	**27**	**15 779**	**14 015**	**17 023**	**13 907**
Saint Lucia	31	-	-	-	4
Area total	**31**	-	-	-	**4**
Morocco	34	4 500	4 500	4 500	4 500
Area total	**34**	**4 500**	**4 500**	**4 500**	**4 500**
Argentina	41	12 584	5 947	2 575	2 575
Uruguay	41	-	-	-	-
Area total	**41**	**12 584**	**5 947**	**2 575**	**2 575**
South Africa	47	1 180	1 200	1 200	1 200
Area total	**47**	**1 180**	**1 200**	**1 200**	**1 200**
Madagascar	51	0	0	0	0
Tanzania	51	0	0	102	486
Area total	**51**	**0**	**0**	**102**	**486**
Indonesia	57	427	384	324	540
Thailand	57	2	1	10	10
Area total	**57**	**429**	**385**	**334**	**550**
China	61	123 670	135 860	122 850	155 790
Japan	61	361 808	412 171	330 549	452 755
Rep Korea	61	114 783	149 132	93 140	125 841
USSR	61	10 804	13 338	15 268	11 538
Other nei A	61	10 754	9 824	5 722	6 653
Area total	**61**	**621 819**	**720 325**	**567 529**	**752 577**
USA	67	-	-	-	-
Area total	**67**	-	-	-	-
Fiji	71	15	173	217	217
Indonesia	71	55 250	72 421	85 092	90 800
Philippines	71	184 410	170 483	222 003	257 305
Thailand	71	4 231	1 154	990	990
Area total	**71**	**243 906**	**244 231**	**308 302**	**349 312**
Kiribati	77	-	1 500	324	411
Mexico	77	7 542	5 479	7 140	8 110
USA	77	-	-	-	-
Area total	**77**	**7 542**	**6 979**	**7 464**	**8 521**
New Zealand	81	0	5	1	0
Area total	**81**	**0**	**5**	**1**	**0**
Chile	87	146 377	95 874	83 643	95 466
Peru	87	245	437	256	267
Area total	**87**	**146 622**	**96 311**	**83 899**	**95 733**
Species total	S	1 076 971	1 112 726	1 022 479	1 250 677
Group total	**S**	**1 076 971**	**1 112 726**	**1 022 479**	**1 250 677**

Source: FAO, 1990.
FAO Yearbook of Fishery Statistics, 1988.

Table 3. World green seaweed and other algae production, 1985–1988. Production by species, fishing areas and countries or areas.

Species	Fishing area	1985(mt)	1986(mt)	1987(mt)	1988(mt)
Green seaweeds				*Chlorophyceae*	
Japan	04	1 043	1 214	1 284	2 207
Area total	**04**	**1 043**	**1 214**	**1 284**	**2 207**
Argentina	41	13	-	-	-
Area total	**41**	**13**	-	-	-
Rep. Korea	61	12 652	13 220	11 248	13 080
Area total	**61**	**12 652**	**13 220**	**11 248**	**13 080**
Fiji	71	19	31	37	37
Area total	**71**	**19**	**31**	**37**	**37**
Species total	S	13 727	14 465	12 569	15 324
Group total	**S**	**13 727**	**14 465**	**12 569**	**15 324**

Source: FAO 1990.
FAO Yearbook of Fishing Statistics, 1988.

Table 4. Aquaculture production by species groups, 1984–87.

Species Groups	1984	1985	1986	1987
		(metric tons)		
Brown seaweeds	2,522,923	2,560,740	2,369,880	2,137,424
Red seaweeds	696,058	664,434	737,284	646,642
Green seaweeds and other algae	4,734	10,658	11,040	7,588
Misc. aquatic plants	222,037	248,356	375,189	347,819

Source: FAO 1989.

Table 5. Main seaweed producing countries by seaweed groups, 1988.

Brown Seaweed	MT (1988)	% of World Total
China	1,298,490	51.5
Korea Rep.	338,805	13.5
Japan	309,253	12.2
Norway	172,148	6.8
France	103,663	4.1
Red SeaweedsMT (1988)% of World Total		
Japan	452,755	36.2
Philippines	257,305	20.6
China	155,790	12.5
Korea Rep	125,841	10.1
Indonesia	90,800	7.2
Green SeaweedsMT (1988)% of World Total		
Korea Rep	13,080	85.3
Japan	2,207	14.5
Fiji	37	0.2

Source: FAO, 1990.
FAO Yearbook of Fishery Statistics, 1988.

Table 6. Main Seaweed Production and Producing Countries.

Main species		Main Producing countries	Main manufacturing countries
Phycocolloids			
Agar	*Gelidium,* *Gracilaria,* *Gelidiella*	Rep. Korea, Chile Spain, Morocco Portugal, (red seaweed)	Japan, Korea Rep., Morocco, Portugal Philippines
Alginate	*Sargassum,* *Laminaria, Undaria Macrocystis* *Ecklonia* (brown seaweed)	USA, Norway, Mexico, Ireland UK, China	UK, USA, Norway Japan, France
Carrageenan	(*E. spinosum E. cottonii*), *Gigartina, Chondus Hypnea* (red seaweed)	Philippines, Canada, Chile, Denmark, Spain	USA, Denmark France, Philippines
Direct human consumption		Japan, Korea, Rep.	Japan, Rep. Korea
		China	China
	Porphyra (nori) *Laminaria* (kombu) *Undaria* (wakame) *Hizikia* (hijiki)		
Animal feed		Norway, Ireland	Norway, Ireland
	Ascophyllum, *Sargassum* (brown seaweed)		
Fertilizer			
	Macrocystis, Ascophyllum	France, UK	France, UK

Source: GLOBEFISH Highlights 3/88.

Table 7A. Agar production in different countries, 1984

Country	Total (MT)
Japan	2 440
Spain	890
Chile	820
Korea Republic	600
Morocco	550
Portugal	320
Taiwan	275
Argentina	197
Indonesia	150
PROChina	140
Mexico	80
USA	70
France	65
Brazil	60
New Zealand	26
Total	6 683

Source: Armisen & Galatas, 1987.

TABLE 7B. JAPAN: IMPORTS OF SEAWEEDS 1984–1987 (Q = MT, V = MILLION YEN).

		1984		1985		1986	
		Q	V	Q	V	Q	V
Hijiki (hiziki fusifome)							
Country							
Rep Korea	2 603	3 165	2 763	2 957	2 775	2 951	3 689
China		63	20	45	11	45	18
Sub-total	**2 666**	**3 185**	**2 807**	**2 968**	**2 820**	**2 959**	**3 664**
Wakame (Undaria pinnatifide)							
Country							
Rep Korea	26 036	8 063	26 692	9 495	25 864	7 002	25 202
Taiwan	-	-	-	-	-	-	18
China		1 411	299	2 515	614	2 894	5 520
Sub-total	**27 447**	**8 362**	**29 207**	**10 109**	**28 758**	**7 512**	**31 992**
Other edible seaweeds							
Country							
Rep Korea	908	285	653	232	1 028	246	1 000
Taiwan	30	20	41	35	17	10	36
China		1 192	440	506	181	571	1 090
Philippines	54	28	23	7	43	12	38
Others	23	6	7	2	35	6	24
Sub-total	**2 207**	**779**	**1 230**	**457**	**1 694**	**468**	**2 633**
Tengusu (Gelidium spp)							
Sub-total	**861**	**313**	**865**	**333**	**1 391**	**385**	**2 089**
Other seaweeds for agar-agar							
Country							
Rep of Korea	49	69	114	195	94	149	189
Taiwan	77	32	33	16	51	20	18
China		-	-	-	-	-	300
Indonesia	69	10	225	39	150	18	309
P'pines	1 470	404	1 071	365	859	230	1 008
Others	7 800	2 368	8 817	3 032	5 389	1 084	5 369
Sub-total	**9 465**	**2 883**	**10 260**	**3 647**	**6 543**	**1 501**	**1 506**
Funori (Cloiopeltis)							
Sub-total	**172**	**279**	**163**	**284**	**160**	**356**	**285**
Non-edible seaweeds							
Country							
Rep Korea	1 495	254	1 504	336	1 568	257	1 334
China		1 867	92	1 691	86	1 428	989
Australia	140	21	193	23	210	17	120
Philippines	861	41	1 049	64	1 181	44	1 462
Other		9 229	750	7 285	641	6 947	5 652
Sub-total	**13 592**	**1 158**	**11 752**	**1 150**	**11 334**	**824**	**9 668**
TOTAL	**56 410**	**16 959**	**56 284**	**18 948**	**52 700**	**14 005**	**56 986**

Note:	Other major exporters are Chile (2 728 MT, 624 million Yen in 1987), Italy (238 MT, 43 million Yen), Turkey (785 MT, 141 million Yen), Brazil (176 MT, 32 million Yen), Argentina (193 Mt, 41 million Yen) and South Africa (850 MT, 149 million Yen)
Note:	Other major exporters of non-edible seaweeds are Norway (1 580 MT, 126 million Yen in 1987) and Chile (3 520 MT, 165 million Yen).
Source:	Fishery Trade Statistics (1987) by Fishery Agency of Japan.

Table 8. Major Agar Exporters, 1986 & 1987.

Country	1986	1987
	(MT)	
Chile	976	873
Korea Rep.	682	749
Spain	555	715
Morocco	510	615
Japan	529	430
Portugal	331	347
Total	**3 583**	**3 729**

Source: Coppen, 1989.

Table 9. Agar Imports: BOBP countries (tons).

		1980	1981	1982	1983	1984	1985	1986
TOTAL			681	489	739	1 236	689	689
Of which by:								
Thailand	209	184	230	307	260	234	252	277
Malaysia	303	253	233	574	256	253	259	279
Indonesia	159	43	262	350	163	170	165	140
India	6	6	4	3	6	3	5	NA
Sri Lanka	2	~(3)	7	~	NA	~	~	1
Bangladesh(1)	2	3	3	2	4	1	3	2

Notes: (1) Derived from exports by Japan, Korea Rep. and Singapore.
(2) Year begins 1 April
(3) <0.5

Source: Coppen, 1989.

Table 10. Agar Exports: BOBP countries (tons).

		1980	1981	1982	1983	1984	1985	1986
TOTAL			2	15	6	15	33	30
Of which by:								
Thailand				~(3)	1	12	12	11
Malaysia(1)			2	12	10	9	12	7
Indonesia				2		1		1
India(2)	2	15	4	1	22	18		NA
Sri Lanka								
Bangladesh	~							

Notes: (1) Derived from imports by Indonesia.
(2) Year begins 1 April
(3) < 0.5

Source: Coppen, 1989.

Table 11. Production of Carrageenan Seaweed World Basis in MT.

Countries	1971	1979	1984
Philippines (*Eucheuma spp*)	500	14 000	25 000
Chile (*Iridaea*)	4 000	6 000	6 000
Canada (*Chondrus crispus*)	6 000	5 700	5 000
Indonesia (*Eucheuma spp*)	4 000	3 500	3 000
Others (*Gigartina acicularies*)	5 500	4 500	4 500
Total	**20 000**	**33 700**	**43 500**

Source: Stanley, 1987.

Table 12. Distribution of Carrageenan Sales.

By End Use	Percent	By region	Percent

Dairy	52	Europe	43
Water gel	16	North America	23
Other food	10	Latin Americal	12
Non-food	22	Far East	20

Source: Stanley, 1987.

Table 13. Japan: Production of Edible seaweed, 1987–1989 (in thousand MT)

		1987	1988
Konbu (*Laminaria*)	123	132	156
Wakame (*Undaria*)	6	7	5
Tengusu (*Gelidium*)	9	9	9
Funori (*Gloiopeltis*)		1	1
Others	29	2	30
Seaweed total	**169**	**190**	**202**

Source: Ministry of Agriculture, Forestry and Fisheries, Japan.

Table 14. Japan: Exports/Imports of Seaweed, 1985–1988.

			1985	1986	1987	MT 1988	1000 USD 1988
Exports Total		-	-	-	-	**57 577**	
Edible	-	-	-	-	46 407		
Dried Nori Total			205 512	195 834	206 808	184 234	11 519
	Taiwan, PC		167 496	173 136	173 000	156 201	9 100
	USA		25 938	16 560	22 901	16 679	1 440
	Others	12 078	6 138	10 907	11 354	1 979	
Dried Konbu			2 772	2 615	1 874	3 607	30 259
	Taiwan, PC		2 699	2 555	1 809	3 558	29 378
	Others	314	530	1 768	754	4 629	
Seasoned Nori Total			256	281	354	385	11 170
	USA		125	143	139	145	6 738
	Others	49	40	105	116	2 566	
	Hong Kong		82	98	110	124	1 866
Imports Total			**33 244**	**33 272**	**36 990**	**34 455**	**93 109**
	Hijiki Total		2 807	2 820	3 564	4 917	34 382
	Rep Korea		2 763	2 775	3 489	4 857	34 269
	Wakame	28207	28 758	31 255	26 930	52 409	
	Rep Korea		26 692	25 864	25 702	22 678	48 529
	Others	1 230	1 694	2 173	2 608	6 681	

Note: Dried Nori (Porphyra), in 1000 sheets.
Source: Trade statistics, Ministry of Finance, Japan.

Table 15. Statistic on the production of cultured seaweeds in China, 1984–1988

	1982*	1983*	1984	1985	1986	1987	1988
Kelp	218 900	231 200	250 661	253 839	203 437	178 900	216 415
Laver	6 800	9 900	12 374	12 367	12 586	12 285	15 576
Other seaweeds	?	?	1 305	3 580	14 286	12 825	12 712
Total	**?**	**?**	**264 340**	**2569 786**	**230 309**	**204 010**	**244 703**

Notes: Seaweeds were mostly sold in domestic market. Laver and undaria ect. were exported in small quantity.

Source: Ministry of Agriculture, People's Republic of China, 1990.

*: Jingwen, 1987

Table 16. Production & Prices of Seaweed in China, 1989–1990.

	Export	Dyeing	Food (Laminaria)	Pharmaceuticals	Others
Amount MT	2 700	1 200	214	5	180*
Price	35 000	36 000	43 000	38 000	
RMB /MT more than 1 000 MT in			*canting ceramic 1988.		
Notes: US$ 1.00 = RM86.00					

Source: Pers. Comm., Lian Peizhi, Xiamen Fisheries College, China, Aug 1990.

Table 17. Republic of Korea: Annual Production of Seaweed by Species 1980–1983 (Net Weight in MT):

	1980		1981		1982		1983	
	Natural	Cultured	Natural	Cultured	Natural	Cultured	Natural	Cultured
Laminaria	2,411	940	375	1,963	761	3,987	440	11,606
Undaria	10,244	196,147	19,313	194,622	6,191	225,045	5,835	237,128
Pachyneniopsis	518	0	419	0	1,162	0	1,018	0
Porphyra	237	56,274	344	80,490	173	79,784	79	87,963
Sea duck weed	5,556	0	3,476	0	2,371	0	621	0
Hijikia	15,853	0	13,743	0	19,849	0	15,335	0
Gelidiun	7,941	560	7,178	88	7,366	0	7,354	3
Other Agar	682	0	207	0	380	0	1,691	0
Ulva	1,518	0	2,132	0	2,150	0	2,532	0
Gracilaria	9	0	20	0	10	0	11	0
Codium	1,227	0	1,017	0	1,792	0	1,161	0
Other seaweed	12,998	3,959	12,860	5,900	3,782	5,719	7,714	10,527
Sub-total	59,194	157,880	61,104	383,063	45,996	314,535	43,794	347,227
TOTAL	317,074		444,167		360,531		391,021	

1984–1987 (Net Weight in MT):

	1984		1985		1986		1987	
	Natural	Cultured	Natural	Cultured	Natural	Cultured	Natural	Cultured
Laminaria	440	11,606	996	11,796	169	9,445	3,761	9,980
Undaria	5,835	237,128	6,380	256,436	8,227	346,434	7,174	235,085
Pachyneniopsis	1,018	0	648	0	813	143	267	261
Porphyra	79	87,963	603	109,819	378	143,369	15	83,287
Sea duck weed	621	0	378	0	181	0	137	0
Hijikia	15,335	0	15,449	8,497	11,630	13,289	21,580	11,572
Gelidiun	7,354	3	4,115	246	5,080	305	9,620	218
Other Agar	1,691	0	1,176	0	266	6	599	14
Ulva	2,532	0	1,524	10,658	1,654	11,040	2,949	7,588
Gracilaria	11	0	2	0	1	0	0	0
Codium	1,161	0	470	0	526	0	656	55
Other seaweed	7,714	10,527	14,372	9	3,944	96	11,798	40
Sub-total	43,794	347,227	46,113	397,461	32,869	524,127	58,556	398,100
TOTAL	391,021		443,574		556,996		456,656	

Table 18. Republic of Korea - Edible Seaweeds Imported/Exported (1985–1987) MT.

Year	Export Vol	Export Value US$	Import Vol	Import Value US $
1985	31 000	53 million	51	244 019
1986	30 000	60 million	26	81 986
1987	32 000	84 million	61	281 075

Source: Republic of Korea, Customs Statistics, 1985, 1986 and 1987.

Table 19. Principal seaweed genera of economic potentials in the ASEAN.

Country	Genera	Uses	Status of Production
Philippines	*Caulerpa*	food	Pond cultur and wild crops
	Codium	food	Wild crops
	Sargassum	alginate	Wild crops
	Porphyra	food	Wild crops
	Gelidiella	agar	wild crops
	Gracilaria	agar, food	wild crops
	Eucheuma	carrageenan food	Mariculture
	Hypnea	food	Wild crops
Indonesia	*Gracilaria*	agar, food	Wild crops
	Eucheuma	carrageenan	Wild crops mariculture
	Gelidiella	agar, food	Wild crops
	Hypnea	carrageenan food	Wild crops
	Caulerpa	food	Wild crops
	Acanthophora	food	Wild crops
Singapore	*Eucheuma*	Carrageenan	Wild crops
	Gracilaria	agar	Wild crops
	Sargassum	alginate	Wild crops
Brunei	*Gracilaria*	agar	Wild crops
E. Malaysia	*Porphyra*	food	Wild crops
	Sargassum	alginate	Wild crops
	Eucheuma	carrageenan	Wild crops
	Caulerpa	food	Wild crops
	Gracilaria	agar	Wild crops
W. Malaysia	*Gracilaria*	agar	Wild crops

FIG 1. MAIN SEAWEED PRODUCERS

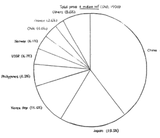
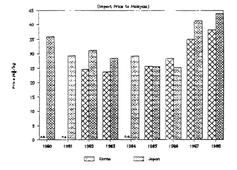
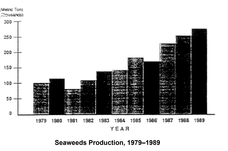


FIG. 2. AGAR STRIP PRICES, 1980–1988



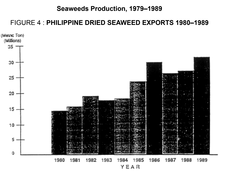
Source: Yahaya & Phang, 1989

FIGURE 3: **PHILIPPINE SEAWEED PRODUCTION 1979 – 1989**



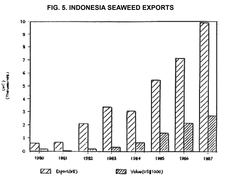
Seaweeds Production, 1979–1989

FIGURE 4 : **PHILIPPINE DRIED SEAWEED EXPORTS 1980–1989**

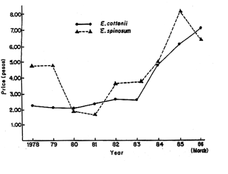


Source: National Statistics of the Philippines

FIG. 5. INDONESIA SEAWEED EXPORTS



Source: Marine Fisheries Research Station Jakarta, Indonesia, 1989

FIGURE 6:

Average Prices Paid for E. cottonii and E. spinosum Delivered to Processors/Exporters in Cebu, Central Visayas, 1978–86 (Prices not Adjusted for Inflation)