The Macroalgae Industry in Maine

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October, 1991

Acknowledgments

This report is based on published materials and conversations with various people with extensive experience in the macroalgae industry. I wish to thank the following for their technical assistance: Andrew Bertocci, The Source Company, Brunswick, Maine; Sam Chapman, University of Maine Darling Marine Center; Lawrence Chen, National Research Council Board, Halifax, Nova Scotia; Shep Erhardt, Maine Coast Sea Vegetables, Franklin; Larch Hanson, Maine Seaweed Company, Steuben; Robert Lewis, Maine Department of Marine Resources; Robert Morse and George Seaver, North American Kelp Company, Waldoboro, Maine; Larry Mulberg, Multichem Company, Ridgefield, New Jersey; Jack Simermeyer, FMC (Marine Colloids), Rockland, Maine; Dr. Robert Vadas, Department of Botany, University of Maine; and Robert Waaland, Botany Department, University of Washington.

I also wish to thank George Kupelian, former Aquaculture Coordinator, Marine Trades Center, Eastport, Maine; Tom Duym, Director, Marine Trades Center, Washington County Technical College, Eastport, Maine; Bo Yerxa, Washington County Technical College, Calais, Maine; David Dow, Sea Grant Marine Advisory Program Leader, University of Maine, for invaluable support and assistance; and Kathleen Lignell, Sea Grant Communications Coordinator, University of Maine, for the final form of this report.

Funding for this project was provided by the Sea Grant Marine Advisory Program of the University of Maine. Additional copies are available for $2.50 each from:

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NA16RG0157-01
TR-MSG-91-1 $2.50

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1 INTRODUCTION

In this world of finite natural resources, humans are continually searching for new sources of food, medical and health supplies, and materials for industrial uses. One resource currently under scrutiny is the macroalgae resource along the Maine coast. Because of the substrate, enormous tidal range, and varying climate, the Bay of Fundy and the coast of Maine have some of the most productive macroalgae crops in the world.

Seaweeds have been harvested for food, fertilizer, and medicinal and industrial uses for hundreds of years. Several, notably dulse *(Palmaria palmata)* and Irish moss *(Chondrus crispus)*, have formed the nucleus of a cottage industry which collects, dries, and sells the seaweeds for food. Rockweeds (*Ascophyllum* spp. and *Fucus* spp.) have been collected for use as fertilizer since colonial times. *Ascophyllum nodosum* is used for packing material for shipping live lobsters and *Ascophyllum scorpioides* is used for sandworms *(Neries virens)* in the marine bait industry. Having recognized the value of its resource and the need of some control of its harvest, Maine is the only New England state which requires a permit for harvesting of seaweeds.

Total use of macroalgae in Maine has varied widely over the years. As recently as the late 1960s, over 400 harvest permits were issued, mostly for collecting Irish moss and selling to FMC/Marine Colloids in Rockland. Total macroalgae harvests of up to 6,000 tons were reported. In the 1980s, it became more economical to import raw material from Indonesia, the Philippines, and Latin America. Another major macroalgae purchaser, North American Kelp, ceased buying several thousand tons of rockweed per year from Maine and imported their raw product from Canada. As a result, the local harvest was greatly reduced, and the number of macroalgae permits purchased in Maine dropped to 35 in 1985 (Robert Lewis, Maine Department of Marine Resources, personal communication, 1991). Presently, North American Kelp is once again beginning to purchase Maine product, FMC/Marine Colloids buys some Irish moss, and a third company, The Source Company, is becoming a major buyer of rockweed. Macroalgae harvesters purchased 138 permits in 1990, and the total harvest for 1991 is estimated at several thousand tons.

One area currently attracting interest is the use of macroalgae for food. A seminar on "sea vegetables" (macroalgae used as food, Madlener, 1977), held at Eastport, Maine on June 16, 1990, brought over 50 attendees from Maine, Massachusetts, Connecticut, New Brunswick, and Nova Scotia. Industry growth in this market has greatly increased in recent years, paralleling growth of the convenience food industry (McLachlan, 1985). Private industry is also becoming increasingly involved. Without a catalyst from the public sector, the macroalgae industry will certainly continue to develop, although it will be at a slower rate.

This report studies the current size, character, and economic value of the macroalgae industry and attempts to forecast its future direction. Because of increased interest in aquaculture, certain algal species are identified that may be particularly well-adapted for culture, either because of economic value and/or ease of domestication. If some of the dominant species in the ecosystem were heavily harvested, this would cause a major impact on the environment. Experience from other heavily harvested areas will be drawn upon in order to predict results if comparable harvests were made along the Maine coast.

2 PHYSICAL DESCRIPTION AND CLIMATE OF THE MAINE COAST

Physical Description

The Maine coast is geographically known as a "drowned" coast. Approximately 17,000 years ago during the last ice age, the area was covered with as much as a mile of ice. As the ice melted, the sea level rose—as did the land at a much slower rate— due to the relief of the weight of the melted ice. The result of wave and wind action on the relatively briefly-exposed shore is not pronounced. The shoreline features prominent granite ledges, rocky headlands, promontories, over 2,000 islands, and limited sandy beaches. It is famously convoluted, with a straight-line distance of 230 miles, and a total shoreline of 3,500 miles. Five major rivers intersect the coast: the Saco, the Androscoggin, the Kennebec, the Penobscot, and the St. Croix.

Climate

The Maine climate is characterized as northern temperate, with an average January temperature of 24°F and an average July temperature of 67°F. Total yearly precipitation averages 45", melted, with 60-90 inches of snowfall. Fog is frequent, occurring 50-90 days per year. Sea water temperatures are influenced by the Labrador Current, ranging from less than 2°C in the winter to 11°C in the summer (much warmer in the shallow, protected bays and estuaries). Salinity in exposed coastal areas averages 32 ppt, with a gradient from fresh to salt water provided where the rivers enter and in some tide pools. Tides range from 9 feet in Portland to over 20 feet in Eastport.

3 SEAWEED BIOLOGY

The 346 species of macroalgae of the Gulf of Maine and the Bay of Fundy are separated into three major groups by general color: the greens (*Chlorophyta*, 88 species); the browns (*Phaeophyta*, 127 species); and the reds (*Rhodophyta*, 131 species) (South, 1976). They exist in general zonations along the shore, with the greens frequenting the shallowest zones, the browns in the next zone, and the reds deepest, with numerous exceptions. A common succession of dominant plants of the extensive, somewhat protected rocky shores is the knotted wrack and rockweed (*Ascophyllum* and *Fucus*) forest in the upper third of the tidal zone, the Irish moss zone with Irish moss *(Chondrus crispus)* and tufted red weed *(Mastocarpus stellata)*, and the kelp zone, another veritable forest located subtidally and immensely productive, consisting primarily of *Laminaria longicruris*.

It is important for the seaweed industry to be acquainted with the general biology and rates of growth of these plants so that maximum sustainable production can be obtained. This knowledge will assist culturists to harvest the plants efficiently and with minimal damage to the ecosystem. For the interested reader, Table 1 lists references which describe the life histories of the economically-important algae.

Table 1. References on Life Cycles of Macroalgae

Kelps

Brinkhuis, B.H., H.G. Levine, C.G. Schllenk, and S. Tobin, "*Laminaria* cultivation in the Far East and North America" in *Seaweed Cultivation for Renewable Resources,* ed. K.T. Bird, pp. 107-146. Elsevier, 1987.

Irish Moss

McLachlan, J., and M.J. Harvey, *Chondrus crispus,* Nova Scotian Institute of Science, Halifax, N.S., 1973.

Laver or Nori

Melvin, Donald J., T. Mumford, William Byce, Makota Inayoshi, and Virginia Bryant, *Equipment and Techniques for Nori Farming in Washington State.* Washington State Department of Natural Resources, 1986.

Rockweeds

Keser, M., R.L. Vadas, and B.R. Larson, "Regrowth of *Ascophyllum nodosum* and *Fucus Vesiculosis* under Various Harvesting Regimes in Maine, U.S.A." *Bot. Marina* (1981) 24: 29-38.

Waaland, J.R., *Seaweed Raft and Farm Design in the United States and China,* New York Sea Grant, 1983.

General

Smith, G.M, *Algae and Fungi,* Vol. 1, McGraw-Hill, 1955.

During the several hundred million years that macroalgae have been around, they have developed numerous techniques for survival. Some are perennial and have a life cycle of growing to maturity and then producing spores, which settle on a substrate, grow for a couple of weeks, and release sperm and egg cells which unite to form a plant that grows into the familiar seaweed (Brinkhuis, B.H. *et al,* 1987).

But there are many variations of the basic life cycle. Some can reproduce by forming special cells which break off of the plant and form new plants, performing the same function as the nursery practice of producing more flowers and shrubs from cuttings. Some have two very distinctive life forms. The *Porphyra,* or laver, is a red alga that spends much of its life as a microscopic filament living inside a mollusc shell or barnacle shell. It matures, gives off male and female cells which unite, attach to a rock (usually), and grow into the familiar laver. It wasn't until the 1940s that scientists learned that the two life forms were actually the same plant.

Some macroalgae in Maine are very productive. Kelp beds produce more vegetation per year than alfalfa fields and tropical rain forests (Table 2). One unexpected fact, personally verified by the rapid fouling of lobster pot rope and salmon cage nets, is that winter growth is very pronounced. The seaweeds exposed during low tide do not perform as well, primarily because of ice damage and exposure to extreme low temperatures of -20°C on occasion.

Table 2. Primary Production of Seaweeds and Plants

(Mann, K.H. 1973. Seaweeds: Their productivity and strategy for growth. *Science* 182: 975-981.)

Plant	Production (gms of C/m-2/yr)
Laminaria (Atlantic Canada)	1200 - 1800
Oak-pine forest (New York)	500
Alfalfa Field (U.S.)	1600
Mature rain forest (Puerto Rico)	1350

The dense vegetative stands of the rockweeds, Irish moss, and kelp zones are ecologically very important to other flora and fauna of the rocky coasts of Maine, providing food and shelter to a number of organisms. Mann (1973) estimates that only 10 percent of the total production enters the grazing food chain, mostly via the green urchin *(Strongylocentratus droebachiensis)* and common periwinkle *(Littorina littorea)*. But these can be in very high numbers. The author has found as many as 3.7 lb/ft^2 of periwinkles, or almost 300 individuals/ft^2. The remaining 90 percent of the production decomposes and enters the detritus chain. The seaweeds serve an important function in this capacity by converting basic raw elements of carbon, nitrogen, oxygen, and numerous minerals into a form usable for other life. Removal by overharvesting greatly alters the equation, changes the biotic community, and can cause much more rapid erosion of the rocky shores.

4 SOME USES OF MACROALGAE

To the unsuspecting consumer, the variety of uses for macroalgae is always startling. In the global market, food is the major use (Waaland, 1981 and Chapman, 1970), but this is hardly the case for North America. In this country, its use as food is rapidly increasing as its health qualities are becoming more well-known. Judith Madlener coined the term *sea vegetable* for edible macroalgae in 1977 to make them more acceptable to the consumer.

Two Maine companies have built their businesses solely on the sea vegetable market. Shep Erhardt, of Maine Coast Sea Vegetables, reports that yearly sales have increased 15-20 percent since the 1970s. Several part-time harvesters in Maine add to the market. Total yearly sales are in the $500,000 range for this part of the Maine macroalgae industry, on a volume of approximately 45,000 lbs.

One type of alga used for food in North America in the rapidly expanding Japanese cuisine market is nori, or *Porphyra*. This market demands special attention because of its current size, rate of growth, and potential. Worldwide sales exceed $2 billion/year. The U.S. has the fastest growing market in the world, with 1990 sales approaching $25 million and growing at 12-15 percent per year. How it pertains to the Maine industry is discussed in the following section under *Porphyra*.

A far more common use of macroalgae from Maine is as food additives. carrageenan, extracted from Irish moss *(Chondrus crispus)* and other algae, has a plethora of uses as a geling agent in various foods and pharmaceuticals. Because of its value, Irish moss is being intensively cultured in Nova Scotia by Acadian Sea Plants, and is the most valuable macroalga harvested in Nova Scotia. It is harvested by hand in Maine and sold to FMC/Marine Colloids of Rockland, Maine, whose factory makes up part of one of the world's largest seaweed companies.

Kelps and rockweeds are harvested in Maine waters for the extraction of algin, which has a wide variety of uses. North American Kelp Company of Waldoboro, Maine, is the primary purchaser.

Rockweeds and knotted wrack are harvested for use as fertilizer and as animal feed. These make up the highest quantity of macroalgae harvested in Maine. The North American Kelp Company and the Source Company in Belfast are the largest buyers in Maine. Large quantities, probably in excess of 1,000 tons, are harvested for packing material for the lobster and marine baitworm industries.

Macroalgae have many other important but low volume uses. Because they concentrate trace elements, historically they have been a source of iodine, potash, and other minerals used in industry and in medicine. A number have been used for drugs, including the following: anticoagulants, antibiotics, antihelmenthes (worms), antihypertensive agents, reducers of blood cholesterol, and dilatory agents (Volesky, et al, 1970). Some exhibit insecticidal tendencies (Arasaki, 1983).

Two other rather exotic uses are also being explored. Because some macroalgae are so highly productive, a number of researchers are studying the possibility of using the production as a source of renewable energy (Gerrad, V.A., 1987). Methane gas is released in large quantities during decomposition of the algae. Another possible use for macroalgae is in the utilization of wastes from salmon mariculture (Levin and McNeil, 1990). Studies are being conducted to determine if the biological wastes of the extensive salmon farming industry can be converted into useful macroalgae for food.

5 DETERMINATION OF CANDIDATES FOR AQUACULTURE

Culturing economically important seaweeds is considered advantageous for several reasons. One advantage is that by culturing the algae in suspended structures away from the rocky substrate, an existing ecosystems is not altered. Another advantage is that harvesting is simple and very efficient. One does not have to wait for the proper tides and risk dangerous wave action, if the algae are cultured on nets or ropes strung horizontally on the surface of protected bays. In general, culture production can be considered supplemental to the existing natural production, if it is not done over existing macroalgae beds.

With the recent explosion of finfish culture on the downeast Maine coast, it is possible that the algae nets or ropes could be placed to take advantage of the waste products generated from these operations. This innovative application is currently being explored in the Pacific Northwest (Levin and McNeil, 1990). These wastes could act as fertilizer for the algae. In the case of producing sea vegetables, the cultured algae can easily be managed to have better form, and the culture sites could be better selected and protected from pollution.

Many species of algae cultured in countries with lower labor costs and a longer growing season would not make suitable candidates for Maine waters. The following criteria for suitability of various algae for aquaculture along the Maine coast are adapted from Gates, J.M., *et al.* (1974). One set of criteria are biological. The algae must be able to reproduce sexually or asexually in captivity, have light intensity and duration requirements readily satisfied, and grow relatively fast. In addition, the algae must have been previously cultured, even on a limited scale, in the New England environment.

The second set of criteria are economical. A suitable species must have an existing high unit price and a large market volume. It is important to avoid the common argument that new products create new markets, which tends to exaggerate the potential of high-unit-priced, low-volume markets of some new products, such as rare photoreceptive chemicals found in some algae and used as tracers in certain medical tests. The high unit price is necessary to justify the capital expense in culturing the algae as compared to the relative low cost of harvesting wild algae.

6 ECONOMICALLY IMPORTANT MACROALGAE IN MAINE

6.1 PORPHYRA Species

Common names: Laver, nori

Description: There are at least four species of *Porphyra* in Maine waters: *P. umbilicalis, P. miniata, P. leucosticta,* and *P. linearis*. They are in the red algae group, with color ranging from dark brown and nearly black to bright red. *P. umbilicalis* and *P. miniata* are most prominent with broad and papery blades, with a thickness of only one to two cells, so thin they are translucent. Both are called laver.

Habitat: *P.umbilicalis* is found in the upper intertidal zone on rocks and mooring balls in protected waters. *P. miniata,* a bright red *Porphyra,* is found at or below Mean Low Water (MLW). *P. leucosticta* is of little economic importance, achieving small size and usually growing on kelp fronds. *P. linearis* also is of small size, having a narrow blade and usually growing just two to three inches long. It is found in turbulent coastal waters at or below MLW. Currently it has no commercial value, but its potential, discussed in detail below, as a nori is enormous.

Four possible species of *Porphyra* exist in Maine waters. The taxonomy of these algae has not been extensively studied in this region. Ordinarily this is of academic importance only, but in the case of *Porphyra,* which has more value worldwide than any other alga and is a $2 billion/year market sold as nori, the importance is magnified.

Nori is a paper-like product made by pressing and drying certain *Porphyra* species into 3-gram sheets 18 x 21 cm in size. They are used in Japanese cooking. Several workers have noted that *P. umbilicalis* has markedly different tastes, depending on location in this area. Dr. Lawrence Chen and Dr. Caroline Bird of the National Research Council of Canada in Halifax, Nova Scotia, feel that the different flavors probably are due to different species, and not due to environmental factors (pers. comm., 1991).

Positively identified *P. umbilicalis* does not make an acceptable nori. Its cell walls are too thick and it has an abundance of an amino acid that gives it an offensive fish flavor (Lawrence Chen, pers. comm. 1991). At least two locations, one near St. Andrews, New Brunswick, and one near Reversing Falls, Pembroke, Maine, have yielded a *Porphyra* similar in form to *P. umbilicalis* but of markedly different taste. No studies as yet have been done to see if these would make acceptable nori.

Uses: Current uses of *P. umbilicalis* and *P. miniata* are as laver, which is air-dried and used in soups, in making laver bread, and as a seasoning for many dishes. When used as nori it has important food values. These include antiscorbutic properties, in preventing beriberi, as an antibiotic, and in reducing blood cholesterol (Arasaki, 1983).

Harvest: Total harvest in Maine is only 1,000-2,000 lbs/year. Demand is higher than this, and Maine Coast Sea Vegetables imports a few hundred pounds from Japan.

Current market: As laver and seasonings, the primary markets of this macroalgae are health food faddists and health food stores. Maine Coast Sea Vegetables ships the product in small quantities to accounts all over the U.S., Canada, and Europe. It is a very minor quantity and there is small market potential for this product.

Prices: Harvesters: $6-7/lb dried

Wholesalers: laver: $12/lb
nori: $12-25/lb, depending on quality

Aquaculture potential: More than any other alga, the *Porphyra* demands attention as a potential economic bonanza for Maine. The current world market of $2 billion/year of nori is comparable to the Atlantic salmon industry. The U.S. market approaches $25 million/year and is growing 12-15 percent/year, virtually all of it imported from Japan and Korea (*Nori Times*). The Japanese harvest of 1991 (the harvest is mostly in January and February) has been devastated by water pollution (Lawrence Chen, pers. comm. 1991). The effects on the world market have not been determined, but they will be major. Large quantities are held in frozen storage and will ameliorate the effect.

Brief history of nori production: The cultivation of species of *Porphyra* for food and medicine dates back to 533-544 in China and over 1,000 years ago in Japan (Chen, et al, 1990). Two species have been bred selectively and domesticated for this use—*P. yezoensis,* a cold water species, and *P. tenera,* a warm water alga. These plants have been selected for rapid growth and late spore development (and thus a longer growing season).

Until the 1940s, the farmers relied on natural "seeding" of their culturing structures, because they did not know where the spores came from. They simply put the structures in habitats historically known to produce nori and let nature take its course, which resulted in enormous fluctuations of harvests. Then Dr. Kathleen

Drew discovered the source of the spores was from a life stage of what was previously assumed to be a different alga, the *Conchocelis* species, that lived inside oyster shells (Drew, 1949). Once this stage was identified, it could be cultured under laboratory conditions, and the plants could be selectively bred for quality and high production. The Japanese government formed a commission, the National Federation of Nori and Clams Fisheries Cooperative (Zen-nori), and it has been very active in the research and development of the industry—the largest agricultural industry in Japan.

Technological research and breakthroughs are continuing at a rapid pace due to high market demand. Also, because water pollution in heavily industrialized Japan is increasing, it is becoming difficult to produce high quality nori. As a result, Japanese companies are looking for alternative sites, and North America, with its vast areas of pollution-free water, is being closely scrutinized. Other techniques are also being developed. Lawrence Chen of the National Research Council of Canada has developed a technique of developing single cell cultures of *P. linearis* (Chen, et al, 1990). It is hoped that in the future the algae can be grown in flasks in commercial quantities, which can be centrifuged and processed into nori sheets.

Only a few of the 70-some species of *Porphyra* are acceptable for nori, which is critical to the potential of Maine production. Of the two local species which achieve acceptable size, *P. umbilicalis* and *P. miniata* both have serious deficiencies in quality or in culturing technique, i.e. it is extremely difficult to get spores. Only *P. linearis* has acceptable quality, in fact, exceeding *P.yezoensis* in many characteristics for tastes. But it has a very short growing season of two months in winter, and it grows only two to three inches long. To be commercially viable, techniques must be developed to increase production, such as the biotechnical techniques of unicell production discussed above. Dr. Chen estimated that commercial production of *P. linearis* could possibly be achieved in five years on culture nets, and perhaps in ten years for unicell production (pers. comm., 1991).

An alternative to this procedure is to culture *P. yezoensis* as has been done in Washington State since 1979 (Mumford, 1987). After a very careful review and study, with input from a dozen world reknowned algalogists, it was determined that importation of unicell Conchocelis of *P. yezoensis* and *P.tenera* would be of insufficient risk to the environment. These cultures were brought from Japan and successfully cultivated in Puget Sound, Washington. Production rates actually exceeded Japan's by a large amount (Japan's average is 4.3 dry ash-free metric tons/ha/yr, while Washington's ranges from 21.4 to 199.6—Mumford, 1987), due to an excellent environment and longer growing season. If cultures of *P. yezoensis* were brought to Maine and the alga grew, a harvestable product could be produced in two months, with continuing harvests every 5-10 days. Water temperatures are adequate from June to December, which is a longer growing season than Japan's.

Several obstacles exist in the successful importation of *P. yezoensis*. Public hearings are currently being conducted to determine if the importation is sufficiently risk free to Maine waters. There is concern that the alga might escape from the culture area and disrupt the environment, and there may be pathogens or other organisms introduced accidentally with the alga. If importation is allowed, problems still exist. Because of a much longer photoperiod during the growing season in these waters, the plants may produce spores too quickly and seriously impair production. Furthermore, diatoms seriously foul the alga. However, management overcomes this by raising the culture nets out of the water for 1-3 hours/day to dry the nets, and thus killing the diatoms. The nori is resistant to drying, and in this area fog frequents the summer season, which would impair drying and seriously effect production. In spite of these obstacles, importation of *P. yezoensis* would be the most promising method for establishing a nori industry.

Economic Impact of nori Industry in Maine

The economic impact of a successful nori industry in Maine cannot be overstated. In 1983, Kramer, Chen, and Mayo prepared an analysis of the nori industry for Washington state. Cash flow estimates and rates for return on investments were conservatively calculated, using only 80 percent maximum production estimates and including long learning curves and state-of-the-art capital investments in boats, engines, and processing equipment. A 200-net farm, covering 16 acres, could produce 2 million, 3 gm sheets and would net the owner over $40,000/year after taxes and expenses, and a 300-net farm of 24 acres would produce 3 million sheets and net over $70,000/year.

One factor preventing Washington from realizing its potential, however, is that lease sites have been nearly impossible to find. Land owners around Puget Sound do not want to look at culturing facilities. In Maine, there are currently 1,100 acres of leased sites for finfish culture. Only one-fourth to one-fifth of the total area of a leased site is used in production, while the remainder is used for moorings. The author believes that the area around the moorings could be used for nori net culture. This would mean that 700-800 acres of leased sites are already available. If only one-fourth of this is used (200 acres), over $2 million in nori might be produced, yielding over $400,000 in net profit. This should result in dozens of new jobs directly in the growing and harvesting of nori, and even more in processing and marketing.

There might be concern about the effect of the new production on the market. The current U.S. market for nori is $25 million/year. Its growth, of 12-15 percent/year, is limited because Japan's production has been limited. Furthermore, the U.S. receives little high-grade nori, which is primarily kept in Japan. The quantities discussed above would enter the market at the "price taker" level, which would not affect the going price because of the low percentage of the total volume of the market. Other markets exist as well. Japan cannot produce enough high-quality nori and would be most anxious to secure such product. In addition, France also has a high market potential.

Summary of Market and Biological Criteria

Market criteria: The nori market, at approximately $2 billion/year, is large enough to support a nori aquaculture industry in Maine. The U.S. currently imports 230 million sheets valued at $25 million/year. Maine's potential nori production of several million sheets per year is a small percentage of total U.S. sale (1-5 percent). Entry level would be at the "price taker" level, not influencing the market. No effort would be needed for marketing. With values of $12 to $25/lb dried weight to the grower, this satisfies the high unit price criterion.

Biological criteria: No commercial attempts have been made to culture Maine *Porphyra*. All of them have been experimentally cultured, and some with great difficulty. Commercial production potential of local *Porphyra* is rated very low, while commercial production of introduced domesticated *P. yezoensis* in Maine has very high potential. Water temperature requirements of 6-14°C occur from May to mid-November.

Recommendations: The huge global market and high unit price satisfy market criteria for artificial propagation. Biological requirements of *P. yezoensis*, a domesticated cold water Pacific Coast species used as nori, seems to be satisfied in Maine waters. If Maine Department of Marine Resources' requirements to prevent escapement or release of foreign organisms into the environment can be satisfied, it is strongly recommended to attempt to culture this alga to establish a nori industry in Maine in less than one year. Further studies to cultivate *P. linearis* for nori culture and to identify other local *Porphyra* for use as nori, are an absolute necessity.

Effects of overharvesting: *Porphyra* is not a dominant plant. There have been no reports of detrimental effects on the ecosystem by overharvesting.

Participating Companies:

Maine Coast Sea Vegetables
Frankin, Maine

Maine Seaweed Company
Steuben, Maine

Erewhon, Inc.
Wilmington, Massachusetts
(warehouse)

6.2 CHONDRUS CRISPUS

Common names: **Irish moss**

Description: This red alga has large clumps of fan-like fronds 3-7 inches tall. The fronds are flattened, and they may be narrow, branched, curled or twisted. The color varies with locality and season, ranging from white when washed ashore on beaches to green and deep red.

Habitat: *Chondrus crispus* occurs abundantly on horizontal ledges at or below Mean Low Water in somewhat protected bays with strong tidal currents. It will grow in water as deep as 60 feet (Mathieson, *et al*, 1972).

Uses: As a source for the valuable kappa fraction of carrageenan, this alga is of great commercial importance.

Natural production: In some areas of New England and Nova Scotia, this is a dominant plant of the shore ecosystem. Mann (1972) measured 20.9 kg. per meter of shoreline, and nearly 4 kg per square meter. It grows 1.1-1.3 gm fresh weight per square cm (11-13 km m-2) in the summer and 3-6 kg m-2 in the winter (Mathieson and Prince, 1973). In Maine it is commonly found with *Mastocarpus stellata*, a similarly shaped but smaller red alga.

Harvest: Commercial harvests are approximately 100,000 lbs. dry weight per year in Maine (Jack Simermeyer, FMC, pers. com. 1991). It is the most important seaweed of commerce in Canada and the Atlantic Coast of North America (McLachlan and Harvey, 1973), where up to 22,770 tons wet weight are harvested (Chapman, 1970).

Processing: Carrageenan is extracted by boiling the algae. When treated with KCL, the kappa carrageenan precipitates out, leaving the lambda fraction of carrageenan in solution (Arasaki, 1983).

Prices: Prices remain stable at about $0.15-.17/lb wet weight.

Market: The global carrageenan market approaches 45,000 tons valued at $250 million/year (Waaland, 1981). Potential for growth remains very high, because of the numerous uses as food additives and its importance in the rapidly growing fast food industry.

Aquaculture potential

Market criteria: The volume of the current market is sufficiently large to consider culturing this alga. One serious detriment is the very low unit price of $0.15-0.17/lb, which would require very efficient culturing techniques. One positive factor is that the kappa fraction of carrageenan is not uniformly produced in nature, and its production has been successfully selected for in its commercial culture by Acadian Sea Plants, Charlesville, N.S. This company has had some success by producing high quality, high yield plants with kappa carrageenan.

Biological criteria: Culturing techniques have been perfected by Acadian Sea Plants, N.S. Efficient production of high quality *Chondrus* is now commercially viable for this company, which was heavily subsidized by the Canadian government in startup and research and development costs. They produce a high percentage of the current market volume, but they are severely affected by natural harvests. This minimizes the potential of other companies in entering this market.

Recommendations: The high market volume and efficient culture techniques argue for intensive culturing, but abundant natural harvests and low unit price argue against such a practice. Because Acadian Sea Plants cultures a large percentage of kappa carrageenan, the market niche of highest potential, this greatly increases market competition and reduces chances of success for other companies entering the market. For this reason, culturing *Chondrus crispus* is not recommended at this time.

Overharvesting: This macroalgae definitely is susceptible to overharvest. If one-third to two-thirds of natural production is harvested in the summer, then it takes five to six months to regenerate. If a comparable harvest is done in the winter, then it takes over a year (Mathieson, et al, 1973). If a full harvest is made, leaving only the holdfast, then it takes one year if harvested in the summer and two years if harvested in the winter. Damage to the holdfast may set back regrowth several years, or permanently (Mathieson, et al, 1973).

6.3 MASTOCARPUS STELLATA

Common name: Tufted red weed

Description: Tufted red weed is a small stiff plant 2-3" tall with flattened and often curled blades. Its color is usually dark reddish to brown, and it grows densely on rocks forming a thick carpet.

Habitat: This weed, along with Irish moss, forms a distinct zone at Mean Low Water between the rockweeds above and the kelp below. Tufted red weed grows better on sloping and vertical rocky substrates while Irish moss is more often found on horizontal ledges. It grows in areas of strong tides and minimal surf action.

Uses: Its major use is as a source of carrageenan, and it has been used medicinally for coughs, and chest and stomach ailments (Walland, 1982).

Production: Stands of 7-8 kg m-2 have been reported (Michanek, 1975).

Processing: It is boiled and carrageenan is extracted from the aqueous solution.

Prices: No prices were given from seaweed buyers. It probably is incidentally harvested with Irish moss and sold at $0.15/lb.

Market: As a source of carrageenan, there is a large world market for this plant.

Aquaculture potential

Market criteria: The carrageenan market meets the volume criterion for potential culture, but the unit price does not. On this basis, it is rejected.

Biological: Even if culture techniques were well-defined and efficient, the large natural production of tufted red weed discourages the culturing of this plant.

Recommendations: Because of the low unit price and large natural production, this alga does not present much potential as a candidate for aquaculture.

Overharvesting: A brief literature search found no reference of damage to the environment or to the natural production by overharvesting, but surely there is potential for damage. This perennial weed grown densely and provides cover and food for numerous organisms.

6.4 PALMARIA PALMATA

Common names: Dulse

Description: The blades are flattened and broad, with numerous forks. Its color is deep red or purple, and the fronds are tough and leathery. Dulse grows to one foot long.

Habitat: This is a common red alga growing near to below Mean Low Waters in somewhat protected bays with strong tidal currents. The area around Dark Harbor, Grand Manan, New Brunswick, grows the most luxuriant stands of dulse. It grows best on long sloping ledges.

Uses: Food.

Harvest: Around 3000 tons wet weight of dulse is harvested each year, mostly on Grand Manan, N.B. Most of the dulse collected in Maine waters is inferior to Grand Manan's quality (Shep Erhardt, pers. comm. 1991). Robert Morse of North American Kelp in Waldoboro, Maine reports that succulent second year growth produces the best dulse and mature growth is too tough. It is possible that the frequent harvesting at Grand Manan sustains higher quality dulse. Better management of Maine's dulse harvest might produce a similar product.

Processing: Dulse is simply spread out on the ground and air dried, and then packaged in plastic bags for distribution. Some is dried and ground for use as a seasoning.

Prices: Harvesters: $4.00/lb. dry wt.
Wholesales: $12.00/lb dry wt.

Aquaculture Potential

Market criteria: With a volume of several hundred tons wet weight and total sales in the several million dollar range, this is not an acceptable level for widescale aquaculture. Robert Morse of North America Kelp feels there is a viable market for dulse as a food additive. Its relatively mild taste and attractive red color make it more acceptable to western consumer than the stronger flavored kelps. Its greatest market appeal is in use as a flavor enhancer in soups and chowders. It could be dried and ground finely and sold at restaurants and institutions for producing a full-bodied chowder with a very short cooking time. Chemical analysis shows it to be an excellent food, high in proteins, minerals and vitamins (Arasaki, 1983). North American Kelp has not pursued this market because of the limited supply of dulse. If production could be dramatically increased by culturing, this market could be exploited.

Biological criteria: Current culturing techniques involve attaching the vegetative stage of the alga to ropes and harvesting the new growth (Waaland, 1983). Hank Stence, of Cooper Island Salmon Inc., Lubec, Maine, has had some success stretching rope at various depths at his Atlantic salmon cage site and collecting natural spores for grow-out (pers. comm., 1991). Another method is to collect small plants and place them in cages suspended in the water column. They are allowed to tumble in the tide and grow quite well (Waaland, *op cit.*).

Recommendations: Because of the high unit price and the potential for market expansion as a food additive, efficient culturing techniques should be developed. This alga presents high potential to the aquaculturist.

Overharvesting: Dulse is a rather slow growing perennial alga. There is a distinct danger of damaging dulse-producing beds. Second year growth is reported to be more succulent and tastier than older growth.

6.5 THE FUCACEAE

Common names: **Knotted wrack *(Ascophyllum spp.)***
Rockweed *(Fucus spp.)*

Description: There are six species of the genus *Fucus,* and one species of *Ascophyllum,* with a couple of different forms, all brown algae and grouped together in this report because of their proximity in habitat. The *Fucus* species generally have dividing, Y-shaped flattened blades, some reaching two feet long. They are not easily distinguished from each other. *F. vesiculosus* has paired air bladders within the blades that "pop" when they are stepped on. *F. spiralis* lacks bladders and is twisted. *F. seratus* has saw-toothed edges on its blades. *F. edentatus*, *F. evanescens*, and *F. filaformis* are separated by the shape of the breeding receptacles (refer to Gosner, 1978, and Abbott, 1978).

The *Ascophyllums* have long fronds without a midrib and narrow, unflattened blades with air bladders occurring throughout the plant. *A. nodosum* is the dominant species of the rockweed intertidal zone. *A. nodosum mackii* and *A. nodosum scorpioides* are small (8") forms.

Habitat: These algae form the prominent rockweed zone of the intertidal region in Maine. This is the generally dark brown area that is very slippery to those walking on rocky shores and ledges. The habitat is too severe for anything to grow in such huge quantities. Exposed to desiccation for up to six hours per tide, they must endure air temperature ranges from -20°F to 90°F, periods of fresh water during rains, and severe ice damage. In spite of this environment, these plants thrive, probably because their dominant presence alters local conditions. Recent studies indicate successful regeneration from spores occurs only in very calm waters, which is created by the dense foliation of the adults. If this canopy is removed, the turbulence increases, and the zygotes cannot attach to the rocks. The foliage also very effectively prevents desiccation and provides insulation. In this self-perpetuating environment, vegetative stands and even individual plants might be hundreds of years old (Robert Vadas, pers. comm., 1991). The rockweeds are very susceptible to severe damage if harvested too heavily.

Uses: Rockweeds have long been used as fertilizer and soil conditioners. In the last few decades they have been increasingly used as an animal feed supplement as a source for micronutrients. Their use has proven to increase milk production in cows (Chapman, 1970), to improve pigmentation in eggs in chickens (Arasaki, 1983) and to improve general health in horses and pets. Finally, they are an important packing material for shipping live lobsters and marine bait worms. A special form of *Ascophyllum* called wormweed *(Ascophyllum scorpioides)* grows in localized areas. It has a golden color with very fine fronds. Its use is exclusively for the sand and bloodworm bait industry. It is reported to impressively increase the survival rates of the worms and improves the marketability. One reason for the lack of a marine bait worm industry in New Brunswick is that this form of *Ascophyllum* is not found in the area (Creaser, 1983).

Production: These algae are very productive. Mann (1972) has measured average amounts of 125 kg/m of shoreline, or 10.67 kg per square meter. Over 500 plants m-2 and a biomass of up to 19 kg m-2 have been measured on the Maine coast (Keser et al 1981). Areas of harvestable rockweeds in the Digby Neck Area, Bay of Fundy, Nova Scotia across from the Gulf of Maine, yield an estimated 57 tons/acres (MacFarlane, 1955).

Processing: Local farmers gather rockweeds for fertilizer and soil conditioner and simply bury it in their gardens. When used as an animal supplement the algae are dried in commercial driers to 10-12 percent water content and milled to various particle sizes. Some is processed into liquid fertilizer. Alginates are extracted chemically for industrial use.

Prices:	Harvesters:	For packaging: $5.00/bushel For other use: $40/ton ($0.02/lb) wet
	Wholesale:	Alginates: approx. $500/ton Meal: $0.50-$5.00/lb, depending on quality and use.

Harvest: The global market of algin, an important derivative of rockweed, is about 15,000 tons, excluding China's production. China is the world's largest producer, but its production is erratic and sometimes used exclusively domestically. China has produced 16,000 tons/year, or equal to the rest of the world, while North

America produces 6,000 tons for algin, including kelps, mostly in California. Rockweed production in Nova Scotia is 1,500 tons. Maine produces only a few tons at the present time for algin.

Total use of rockweeds as fertilizer and feed supplements is estimated at about 2,000 tons/year. A more important use by weight is as a packaging material. The U.S.D.A. estimates that 3,000 tons/year valued at $500,000, are collected by 138 licensed commercial harvesters in Maine (Robert Morrill, U.S.D.A. Fisheries specialist).

Potential market: The algin market is growing at barely one percent/year. Its use in foods and pharmaceuticals is growing, but its use in textiles is decreasing (Larry Mulberg, Multi-Chem Company, pers. comm. 1991). As a feed supplement and fertilizer, it is marketed as "natural" and safe, and this market is growing. The market potential as a packing material is dependent on successful lobster and marine worm bait industries.

Aquaculture potential

Market criteria: With a global volume of 15,000 tons/year and values in the tens of millions, the market is large enough. The unit price of $.02/lb wet weight is not acceptable, however.

Biological criteria: The Hydrobotanical Co. of Long Island, New York, patented an onshore process of culturing rockweeds in the 1960s. Growth was excellent during cool weather, but it was very poor during the summer. Production costs proved to be unprofitable.

Recommendations: Because of the very poor unit price, this is rejected as a candidate for aquaculture. Only if an as-yet-unidentified micronutrient of trace element, whose production might be enhanced by culturing, is found will the recommendation change.

Overharvesting: There is concern about the damage that can be done by overharvesting. Macfarlane (1955) wrote that at least seven inches of the weed must remain intact for the weed to regenerate itself in three years. Dr. Robert Vadas, University of Maine, Orono, feels strongly that leaving fourteen inches is more productive and less damaging to the environment (Keser, et al, 1981). Pritz (1955) found that if only 2.5" is left, there was no recolonization even after eight years, and the habitat was altered.

The Protan Group, a Norwegian-based company, extensively harvests rockweed in Europe and New Brunswick, and it carefully manages the resources. They cut on a three-year rotation, allowing three years growth before returning to a previous harvest site. Some locations in Maine can be successfully harvested on a two-year cycle (Robert Morse, NAK). Two-year growth sometimes produces a higher yielding algin plant. Locations that are less exposed to ice damage and freshwater can often produce good crops on a two-year rotation. Dr. Vadas emphasizes that the rockweed ecosystem is very sensitive, and, in fact, some plants may be several hundred years old. If harvested too heavily, the area will be severely altered. Great care must be taken to prevent this.

Participating companies:

North American Kelp
Cross Street
Waldoboro, Maine

The Source Company
Brunswick, Maine

And virtually every distributor of live lobsters
and marine bait worms in Maine.

6.6 LAMINARIA LONGICURIS

Common names: Oar weed, hollow-stemmed kelp

Description: This brown kelp has a long narrow stem transforming into a flat blade with no midrib. It can reach 36 feet long.

Habitat: A dominant plant of the coast, it grows in dense forests below mean low water along much of Maine's shores.

Uses: As a group, kelps are harvested and cultivated more by volume than any other macroalgae in the world (Brinkhuis *et al*, 1987). They are a prominent source of algin and food in the Oriental market. Studies have been made to determine their feasibility for use as energy in the production of methane gas (Neushal and Harger, 1987 and Brinkhuis, *et al*, 1987). Traditionally they have been a source for iodine and potash, their stipes used to open wounds and cervical dilation and in inducing abortions. Oarweed is harvested as a food in Maine for health food stores and sold as kombu. As with the other kelps, it is a natural source of MSG.

Natural production: This macroalga is one of the most productive plants in the world. Standing crops of 20-29 km m-2 have been measured, more productive than oak forests, tropical rain forests and alfalfa fields (Table 1—Mann, 1973). Mann (1972) has measured 534 kg of oarweed per meter of shoreline. A closely related species, *L. saccharina,* has been studied as a source of renewable energy in Long Island (Brinkhuis, *et al*, 1987).

Harvest: Harvests in the Atlantic Provinces of Canada and Maine are reported to be around 6,000 tons/year, barely one percent of the total production of 500,000 tons/year (Waaland, 1981). Approximately 3,000 lbs/year is harvested for the kombu trade, which is the only harvest that can be verified presently in Maine.

Processing: Locally, it is air-dried and sold whole or milled and sold as seasoning. Processing for algin requires large amounts of electrical energy and fresh water.

Prices: Harvesters: for food: $4.00/lb dry
Wholesale: $12.00/lb
For industrial use comparable to rockweed, $.02/lb wet.

Market: *Laminaria's* market for use as food is limited to the Oriental and health food markets. This currently is only in the $50,000/year range for this region. As a source of algin, the abundant local *Laminaria* provide little advantage in the global market because energy costs in Maine are very high, and environmental constraints on the usage of large quantities of fresh water are expensive. Further testing is needed to determine if production is high enough to be competitive as a source of methane gas for energy (Brinkhuis, *et al*, 1987).

Aquaculture potential

Market criteria: Huge global volume estimated at 2 million M.T. wet (Brinkhuis, *et al*, 1987) easily satisfies the market volume criterion, but the small unit price of pennies per pound, for use industrially minimizes its potential. When used as food, however, the unit price of $4.00/lb satisfies this criterion but the small volume sold locally is unacceptable. Quality of *L. longicruris* is said to be inferior to the *Laminarias* used in Japan for kombu (*Seafood Leader*, March-April 1989), so entry into this market may not be possible.

Because of the huge supply of *L. longicruris*, the current market cannot be limited by supply, but only by demand. Thus an increase in the local supply by culturing for kombu is not justified. Its only advantage is that it would be much easier to harvest from suspended ropes than from subtidal rocky shores.

Biological criteria: The life cycle and techniques for culturing are readily known (Brinkuis, *et al*, 1987, Neushal and Harger, 1987). Production of a very closely related alga *(L. saccharina)* on ropes in Long Island Sound were estimated at 7-12 dry ash-free kg/ha, or similar to Japanese production. Potential economic viability must be in conditions where light is the limiting factor and not nutrients (Gerrad, 1987). If nutrients such as N, P, K, are limiting and growth would be greatly enhanced by fertilizing, the production would not be economically viable (Gerrad, 1987).

Recommendations: Large scale culture of *L. longiscruris* is not recommended because of the huge quantities of natural production and the huge global supply of kelps in the macroalgae market. However, because of the ease of culture and low capital requirements, small scale culture or culturing with other species (polyculture) is economically viable for sale in the high unit price, low volume food market.

Overharvesting: The author found no reports of overharvesting by humans, but the green sea urchin, *Strongylocentrotus droebaciensis*, is capable of decimating entire kelp beds.

Participating companies:

Maine Coast Sea Vegetables
Franklin, Maine

Maine Seaweed Company
Steuben, Maine

6.7 LAMINARIA DIGITATA

Common name: Horsetail kelp

Description: Horsetail kelp has 6-30 flattened blades growing from a single stipe. It grows to three feet long.

Habitat: This plant is found most abundantly below Mean Low Water in strong tidal and heavy surf zones. Occasionally it occurs in tidal pools.

Uses: In the health food industry it is used as a flavoring in soups and especially in baked beans.

Production: Only several hundred pounds of *L. digitata* are harvested in Maine each year. Maine Coast Sea Vegetables imports 10,000 lbs of cultured horsetail kelp from Iceland to be milled and used as a seasoning. It is more economical to import the plant than to harvest locally.

Processing: This kelp is air-dried, most commonly hung over a clothesline, and packaged in plastic bags. Sixty lbs of wet kelp, or one bushel, yields about 4 lbs of dry.

Prices:	Harvesters:	$4.00/lb
	Wholesale:	$12.00/lb

Market: The U.S. market is in the tens of thousands of dollars/year, mostly as a seasoning. Nearly all of the *L. digitata* used is imported because it is cheaper than locally harvested product. Promoted as a health food, its potential for growth is good in the small volume market of seasonings.

Aquaculture potential

Market criteria: The small volume is insufficient to support large-scale operations, but the unit price of $4.00/lb is attractive.

Biological criteria: The culture techniques are very efficient and have low capital requirements. *L. digitata* is extensively cultured in Iceland. Techniques for all of the kelps are similar, with the spores "seeded" to rafts of ropes.

Recommendations: For small scale operations and as a candidate for polyculture, this kelp shows promise. Production costs should be competitive to those in Iceland and the potential of entering the 10,000 lb/year market of seasonings sold by Maine Coast Sea Vegetables exists. A unit price of $2.00/lb might be more realistic.

Overharvesting: As with the other kelps, overharvesting, or more specifically overgrazing by the green sea urchin, can occur.

Participating companies:

Maine Coast Sea Vegetables
Franklin, Maine

Maine Seaweed Co.
Steuben, Maine

6.8 ALARIA ESCULENTA

Common name: **Edible kelp, wakame**

Description: This single-bladed kelp has a midrib and small "leaflets" near the base of the stipe. It is a very robust plant, growing to ten feet in May and June.

Habitat: Edible kelp is often found with horsetail kelp, in strong tidal areas below Mean Low Water in strong surf.

Uses: The scientific name "esculenta" means "edible" and describes its primary use.

Production: Only a few thousand pounds is harvested in Maine. Worldwide culture production of this and similar "wakames" for food is several hundred thousand tons, second only to nori.
Processing. It is air-dried and packaged in plastic bags. 60 lbs. of wet wakame yields about 4 lbs dried.

Prices:	Harvesters:	$4.00/lb dry
	Wholesale:	$12.00/lb

Market: The U.S. market with Orientals and health food stores for this tasty plant is not large.

Aquaculture potential: The potential of this plant is the same as with the other kelps. Easily and efficiently cultured on rafts of rope, this alga is constrained only by the small local market and huge production in Asia for the vast Asian market, making entry of a North American product unlikely. If a market as a health food seasoning is further developed, potential exists as one of several species to be cultured at one site.

Participating companies:

Maine Coast Sea Vegetables
Franklin, Maine

Maine Seaweed Company
Steuben, Maine

6.9 ULVACEAE

Common name: **Sea lettuce**

Description: There are at least two local representatives commonly called sea lettuce, *Ulva lactuca* and *Monostroma spp*. They are both bright green sheets and two of the most familiar of the macroalgae. *Ulva* can be differentiated from *Monostroma* by the fingerprint test. If fingerprints can be seen through the translucent plant, it is *Monostroma*. If they can't, and the texture is similar to wax paper, it is probably *Ulva*.

Habitat: These macroalgae are found in a variety of places, from exposed rocks to tide pools to muddy flats where fresh water is abundant. They thrive in nutrient-rich, i.e. polluted, waters.

Uses: Both are locally used occasionally in salads. *Ulva* is used as a fodder in Europe and the potential exists to be used as a source of methane gas in Venice, where the polluted waters have caused huge blooms of *Ulva* in the canals (John Merrill, pers. comm. 1990). *Monostroma* has a milder flavor and is more acceptable for food. Waaland (1981) lists *Ulva* as being used for burn treatments.

Natural production: Locally in nutrient-rich, low-salinity tidal areas, abundant growth can occur.

Current harvest: Presently the *Ulvaceae* are harvested only for private consumption. Volume is insignificant.

Processing: *Monostroma* can be used fresh in salads. The sea lettuce is used fresh as a fodder as well, or dried, milled, and added to animal feed.

Market: Presently there is virtually no market for Maine sea lettuce. It is included in this report because it is familiar with most beach combers, it is edible, and has occasional use as an animal feed. In Europe it is used more widely as a fodder, but indigenous production is more than adequate to meet its demand.

Aquaculture potential: Because no real market exists, the sea lettuce has no culture potential at this time.

7 MACROALGAE OF POTENTIAL ECONOMIC IMPORTANCE

The following macroalgae are used in other areas of the world and occur in Maine waters, but they have not been commercially harvested. While possible candidates for aquaculture, they can generally be more efficiently grown in warmer waters, or in countries with much cheaper labor.

7.1 ENTEROMORPHA INTESTINALIS

Common names: Green confetti, hollow green weed

Description: A grass-green macroalga with an unbranched, one foot long hollow thallus, this plant sometimes virtually covers clam flats in the late winter and early spring.

Habitat: Aside from the tidal flats mentioned above, it occurs in tide pools and areas where fresh water enters the coast, especially in areas of sewage effluent.

Uses: This plant shows antibiotic properties (Vadas and Ring, 1968). Similar species are used in Japan as food (green nori). When dried it has a pleasant spice-like aroma, and it is said to remove fishy tastes from other macroalgae when used as animal fodder (Sam Chapman, pers. comm. 1991).

7.2 AHNFELTIA PLICATA

Common name: Wire weed

Description: Wire weed has a consistency of steel wool. It is almost black when fresh, and it bleaches white when washed up on beaches. This plant grows to 8 inches. Its branches are less than 1/16" thick.

Habitat: Wire weed occurs occasionally in cold tidal pools in eastern Maine.

Uses: This alga, along with *Gracilaria foliifera* (next section) is an "agarophyte," or a source for agar, which is used in huge quantities as a medium for unicellular and bacterial culturing in industry and medicine, as a stabilizer in jams and jellies, and in the cosmetic industry. The U.S. uses in excess of 600,000 lbs of agar per year (Vadas and Ring, 1968).

7.3 GRACILARIA FOLIIFERA

Common name: Graceful red weed

Description: This is another bushy red weed of varying color growing to one foot. Its branches are much wider than wire weed, reaching 1/2", and at least some are flattened, a key distinction from wire weed.

Habitat: Mostly a warm water alga, graceful red weed occurs locally abundant in shallow bays in southern to central Maine.

Uses: This alga is used as a source of agar. Similar species are farmed extensively in the Philippines and Indonesia.

7.4 DEVALERAEA RHODOMELA

Common names: **None**

Description: *Devaleraea* is a hollow-bladed, one foot long red plant with at least a few lateral branchlets. *Rhodomela* is a bushy red plant differentiated from graceful red weed by having bundles of filaments bound together. It reaches 18" long.

Habitat: *Devaleraea* is common on rocks and jetties in turbulent waters. *Rhodomela* may be epiphytic, or free floating along the shore.

Use: Both algae exhibit antibiotic properties (Vadas and Ring, 1968).

8 FUTURE OF THE MACROALGAE INDUSTRY IN MAINE

Because of the increasing interest in macroalgae as food and the high unit price of these products, it seems inevitable that most of the growth of the industry will be in this direction. Harvesting wild crops of macroalgae is cost effective for a few of the kelps and for dulse, but overharvesting and damage to recruitment is a danger. This can be obviated by culturing these plants on ropes stretched near the water surface. Because some of the important macroalgae used for food do not grow in easily harvestable areas or quantities, they definitely are prospects for aquaculture. These include the *Porphyras*. If a local or imported *Porphyra* can be grown in Maine waters suitable for nori, a potential industry rivaling the Atlantic salmon industry could be developed.

Huge quantities of rockweeds also exist on Maine shores and are attracting attention from commercial harvesters from Norway to Canada, as well as two local companies. These macroalgae have been incorrectly harvested in a few other areas of the world. It is imperative that the current and potential harvesters be guided and regulated with the most current and productive techniques that ensure proper recruitment.

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Table 3. Economically Important Macroalgae in Maine

Name	Current Harvest (dry)	Price (lb)	Use	Market Value ($)
Porphyra	1-2,000 lb.	$6-7.00	food	20-25
Chondrus crispus	100,000	.60-70	carrageenan	200
Mastocarpus	—	—	—	—
Palmaria palmata	>5,000	$4.00	food	>50
Fucaceae	6,000,000 (wet)	$.02 (wet)	fert., feed algin	1-2000
Laminaria longicuris	4,000	$4.00	food, algin	50
L. digitata	>1,000	$4.00	food	>5
Alaria esculenta	1-2,000	$4.00	food	20
Ulvaceae	—	—	food	—
Enteromorpha Intestinalis	—	—	antibiotic feed	—
Ahnfeltia plicata	—	—	agar	—
Devaleraea	—	—	agar antibiotic	—
Rhodomela	—	—	antibiotic	—

Totals: Approx. 6 million lbs. $2-3M

About the Author

Stephen Crawford is owner of International Maine Resources, an aquaculture service company, and he is adjunct professor at Washington County Technical College in Calais, Maine. He studied fisheries at the University of Rhode Island and the University of Oklahoma. Crawford has raised several species of fish both as a Peace Corps volunteer and as a member of its training staff in India, Nepal, and the Philippines. He left eleven years of catfish farming and processing in Oklahoma to move to Downeast Maine, where the potential for a coordinated multispecies aquaculture project with algae, shellfish, and finfish is very high. Crawford lives with his wife and two daughters in Eastport, Maine, where he explores the abundant flora and fauna of the Cobscook Bay intertidal zone.