Bulletin

of the
Aquaculture Association of Canada

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Édition 99-1, mars 1999
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AAC gratefully acknowledges the Canadian Centre for Fisheries Innovation (CFFI), St. John's, Newfoundland, for funding this issue of the *Bulletin* and provinding financial support for the authors to present their papers at Aquaculture Canada '98.

Front cover: *Laminaria digitata* is a common brown alga in the Atlantic Provinces of Canada and the northeastern United States. It is harvested for the production of alginates, fertilizers, and nutriceuticals. Back cover: Net seeded with *Porphyra leucosticta*, a red alga common in the Atlantic Provinces and northeastern United States from late fall to summer. It is primarily epiphytic on other algae in lower eulittoral and upper subtidal zones. *Porphyra leucosticta* is included in a cultivar-improvement program for local Porphyra species. *C. Yarish photos.*

Aquaculture Canada '99

16th Annual Meeting of the Aquaculture Association of Canada

and the

Pacific Aquaculture Exchange Trade Show

October 26–29, 1999
Victoria Convention Center
Victoria, British Columbia

Conference Information:
Linda Townsend
Fisheries and Aquaculture
Malaspina University–College
900 Fifth Street
Nanaimo, BC V9R 5S5

Tel: 250 741-8708
Fax: 250 755-8749
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Trade show Information:
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www.mi.mun.ca/mi/aac/ac99.htm

"Aquaculture — A Future in Fisheries"

President's Message

At the mid-year meeting of the Board of Directors in January 1999, President Yves Bastien organized a strategic planning session to examine and evaluate whether the Aquaculture Association of Canada (AAC) should pursue any new initiatives after fifteen years of existence. A number of issues were discussed and a strategic plan is now being drafted by Ted White. I will discuss a number of the issues in future columns, but I want to focus on one principle area in this article, namely communications.

Information and technology exchange is one of the key mandates of the Aquaculture Association of Canada and the *Bulletin* is our main vehicle for published material. The *Bulletin* has now taken on a slightly different look. It is larger, primarily to accommodate formatting of figures and tables. There will also be an increasing amount of bilingual content, starting with the cover and masthead. The *Bulletin* has been quite successful in publishing the proceedings of a number of workshops held throughout Canada, most in conjunction with Aquaculture Canada meetings. The topics covered in the individual bulletin's have been diverse, ranging from sea urchins to seaweeds, marine finfish, broodstock management, etc. AAC will continue offering coverage on a wide range of topics of interest to members, but it will also begin including more news of the association and other related activities (starting with a regular President's column).

A new initiative being undertaken is to recognize and increase awareness of the achievements of the members of the Aquaculture Association of Canada. Two new awards will be instituted, the first a Research Award of Excellence and the second an Honourary Life Member Award. The Research Award of Excellence is to recognize high quality, innovative current research that has or may have a signifcant impact on the aquaculture industry in Canada. The Honourary Life Member Award is being established to recognize a person for their lifetime contribution in the field of aquaculture or to the association. Nominations for these awards should be sent to my attention.

An initiative that was approved at the Board meeting concerns commercial trade publications. There are now a number of Canadian commercial trade publications available and it was decided that all commercial publishers should have fair and equal access to offering their publications to the AAC membership. Before the end of this year, renewing and new members will be able to subscribe to a number of these publications on the membership form. The cost will be in addition to the regular AAC membership fees.

In closing, Yves Bastien resigned from the AAC Board of Directors at the end of our mid-year Board meeting as he had been appointed as the new Commissioner of Aquaculture Development. On behalf of the Board and the Aquaculture Associaiton of Canada, we thank Yves for all his efforts over the years and look forward to working with him in his new role.

— Jay Parsons

Call for Nominations
Research Award of Excellence

The award recognizes high quality, innovative research that has the potential to have a significant impact on the the aquaculture industry in Canada.

Nominations, including a brief resume and description of the research program, should be sent to Dr. Jay Parsons (jay.parsons@mi.mun.ca).

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Introduction

A one-day workshop entitled "Coldwater Seaweed Aquaculture" was convened at Aquaculture Canada '98— the 15th Annual Meeting of the Aquaculture Association of Canada — in St. John's, Newfoundland, on June 3, 1998. The Canadian Centre for Fisheries Innovation of St. John's provided financial support for the invited speakers to travel to the workshop and for the publication of these proceedings. The objective of the workshop was to bring a number of the leading research scientists from North America together to explore the possibilities for seaweed culture in the Atlantic and Pacific regions of Canada. The session also provided a venue for existing and potential seaweed aquaculturists, government personnel, and funding agencies to learn about seaweed culture and discuss the opportunities for and constraints to establishing a thriving seaweed industry in Canada's coastal waters.

Globally, the production of seaweeds from aquaculture is over 7.7 million metric tonnes and represents about 25% of the total annual aquaculture production by volume (Michael New, 1999, *World Aquaculture* 30(1):8-13, 63-79). While wild seaweeds are harvested commercially in Canada, there is little production from aquaculture. Seaweed aquaculture does, however, offer a new and technically viable diversification of the resource use of our maritime environment. In particular, the polyculture of seaweeds in conjunction with finfish and (or) shellfish represents an important sustainable approach to aquaculture in our aquatic environment.

The workshop presentations focussed on the history and principles of seaweed culture in Canada (J.S. Craigie), new uses and approaches for cultivating kelp (L. Druehl), an integrated approach to seaweed culture (T. Chopin and C. Yarish), potential of seaweed cultivation in Newfoundland (R. Hooper), commercial cultivation of nori in New England and the Maritimes (L. A. Levine), domestication of nori (C. Yarish et al.) and strain improvement and genetic modification to improve the success of seaweed culture and development of new products (D. P. Cheney). The workshop resulted in new linkages between the aquaculture industry and seaweed researchers, the initiation of new projects, and the highlighting of new research opportunities.

It is interesting to note that this workshop occurred a few months after a similar special session was held at Aquaculture '98 in Las Vegas in February 1998. Several of the presentations from that session were published in *World Aquaculture* in volumes 29(4) (1998) and 30(1,2) (1999). Let us hope that these two seaweed culture sessions mark a new and expanding opportunity for the industry in Canada.

— *G. Jay Parsons*

Coldwater Seaweed Aquaculture Workshop

Organizing Committee

G. Jay Parsons, Centre for Aquaculture and Seafood Development, Marine Institute of Memorial University, St. John's

Steve Moyse, Newfoundland Aquaculture Industry Association, St. Alban's

Brian Burke, Canadian Centre for Fisheries Innovation, St. John's

Background and Principles of Seaweed Aquaculture

James S. Craigie

Cultivation of seaweeds for food and industrial uses is a relatively recent development. Seaweed aquaculture in Atlantic Canada can be traced to the selection of the T4 cultivar of Irish moss in 1970 at the Atlantic Regional Laboratory in Halifax. Three companies currently culture red seaweeds in Canada. High seaweed productivity results from light energy being delivered within a temperature and nutrient regimen suitable for optimal seaweed growth. Sufficient natural light is available for this purpose in the early months of the year in Atlantic Canada, but low coastal water temperatures during this period can result in suboptimal production.

Introduction

Cultivation of seaweeds for food and industrial uses is a relatively recent development compared to the farming of land plants. In the present context, the only seaweeds to be considered are the macroalgae, although some cultivation of other plants such as seagrasses does occur. According to Tseng,[1] seaweed husbandry was initiated in China more than 200 years ago to augment natural recruitment of red algae belonging to the genus *Porphyra*. These seaweeds continue to be highly regarded human foods and are extensively cultivated in Japan, where the nori business is currently valued at US$2 billion per annum. The major growers also include Korea and the People's Republic of China.

Two other red seaweeds are cultivated on a large scale, but are used to supply the hydrocolloid market. The successful farming of *Eucheuma* spp., including *Kappaphycus* (*Eucheuma*) *alvarezii* in the Philippines, displaced Canadian *Chondrus crispus* from much of the world carrageenan market during the 1970s. Development of techniques for propagating *Gracilaria chilensis* and the extensive farming of this species in Chile during the 1970s and 1980s[2] did much to stabilize the supply of raw material for the agar extraction industry.

Brown seaweeds belonging to the Laminariales are cultivated for foods as well as for their industrially valuable alginates. From about 1950 to 1980, the People's Republic of China developed and refined techniques for the mass culture of *Laminaria japonica* and today is the world's largest producer, growing about two million metric tons annually. Substantial quantities of several *Laminaria* species and *Undaria pinnatifida* are also grown in Japan where they are important food products. Numerous brown, green, and red seaweed species are now being cultivated in a number of countries either for experimental purposes or for local markets.

Seaweed Cultivation in Canada

The rapidly escalating worldwide demand for carrageenan in the mid-1960s focused interest on the cultivation of Irish moss in Canada. Coincidentally, F. N. Woodward,[3] in a special lecture at the Vth International Seaweed Symposium in 1966 in Halifax, NS, pointed out that the development of algae as crops might follow the pattern of agricultural plants. Arthur Neish and his colleagues succeeded in propagating a stable cultivar (T4) of *Chondrus crispus* (Irish moss) in 1970.[4,5] By 1973, two commercial firms had established experimental facilities to exploit this development: Marine Colloids Ltd. of Rockland, Maine installed culture tanks at Meteghan, NS, and Genu Canada at Point Sapin, NB. The latter company moved their culture operations to Hey Point near Halifax in 1975, and terminated experimental work in 1978. The experimental facility of Marine Colloids was moved to Charlesville, NS, in 1978, and in 1981 the company was acquired by Acadian Seaplants Ltd., of Dartmouth, NS, who continue to cultivate Irish moss. Initially the Irish moss was simply dried and exported as a source of carrageenans. Today the seaweed is cultivated and processed on site to meet rather stringent specifications as a human food. A second Nova Scotian seaweed grower, Ocean Produce International, currently cultures a special dulse (*Palmaria palmata*) in greenhouse tanks near Shelburne. The product is marketed principally as the fresh vegetable Sea Parsley™.

Another red alga, *Gelidium* sp., is being cultivated in Bamfield, BC, by Marine BioProducts International using the basic technology for Irish moss cultivation. In this case, the company has developed a process to produce agar of very high quality for microbiological and biotechnological applications. The cultivation of brown seaweeds in Canada has been developed by Canadian Kelp Resources of Bamfield, BC, and their success in growing kelp sporelings is described elsewhere in this mini-symposium.[6]

Influence of Light and Temperature

Seaweeds are, virtually without exception, photoautotrophic plants, which means that they are fully capable of utilizing light to convert simple inorganic substances into biomass. In that respect, their cultivation is analogous to the hydroponic culture of land plants. The correct balance of macro- and micronutrients in available forms is necessary for sustaining high levels of production. The ability to control or manage weed species in cultures is essential to success. Similarly, the seaweed farmer must be able to minimize the depredations of animal grazers, and of bacterial and fungal pathogens.[7,8]

Given that adequate nutrient levels can be supplied, the two key physical requirements of temperature and light must be considered. Energy for biomass production is obtained solely from light in the photosynthetically active region (PAR) of the spectrum (400-700 nm). To maximize production, the seaweed culture should be managed so that it responds in a direct linear manner to increased light as has been accomplished with Irish moss.[9] Continuous artificial light can be useful in special circumstances where very rapid propagation is required. Net production of live Irish moss biomass has been sustained at 4 kg m^{-3} wk^{-1} under such controlled conditions.[10]

Seaweeds of Atlantic Canada include temperate to boreal species. Virtually all can withstand temperatures to the freezing point of seawater (minus ~1.9°C), and some such as *Fucus* sp. and *Porphyra* sp. will resume growth even after being frozen for long periods. Species inhabiting the low littoral and sublittoral zones tend to be less tolerant of temperature extremes. However, temperatures for optimal seaweed growth are more restricted than those required for survival. For example, small temperature increments affect relative growth response of Irish moss much more at low temperatures than in the middle range of the temperature-growth curve (Fig. 1). While species to species differences will occur among seaweeds, the general growth-temperature response pattern observed with Irish moss can be expected.

Outdoor cultivation of seaweeds in cold climates requires a management protocol that optimizes the conversion of light energy to biomass. Factors affecting this process have been discussed in several recent reviews.[11-13] Irish moss in outdoor tank culture in Nova

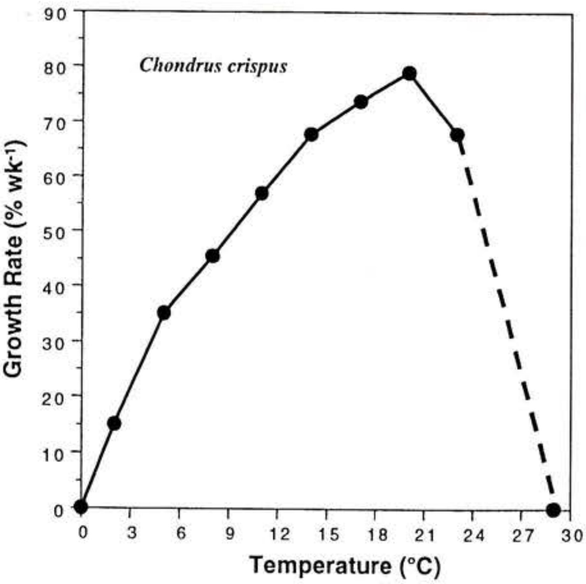

Figure 1. Temperature-growth response of *Chondrus crispus* (Irish moss) (adapted from Enright and Craigie[14]).

Scotia shows net production during each month of the year, with an annual productivity comparable to that of highly productive terrestrial species.[8] In open pond systems without nutrient limitation, maximum Irish moss production is obtained for approximately three months beginning in mid-June, when the water temperature remains above ~12°C. Production then declines smoothly, especially after mid-September, due to ever shorter photoperiods (Fig. 2) until freeze-up in December.

As daylight returns in late winter and spring, significant growth does not resume in outdoor ponds until early May, when the average water temperature consistently exceeds about 5°C. Light saturation for growth of Irish moss, where nutrients and temperatures were not limiting, required a minimum of about 4 MJ m^{-2} d^{-1} of photosynthetically active radiation (PAR) in natural light.[14] Figure 3 shows that 4 MJ m^{-2} d^{-1} of PAR (= 9.3 MJ m^{-2} d^{-1} of total solar radiation) is available beginning in March, even as far north as Frobisher Bay (63.45°N). However, the water temperatures pertaining during this period are well below those required to support optimal growth of this seaweed. It may be seen in Figure 1 that net production of Irish moss doubles between 3°C and 6°C, and doubles again between 6°C and 15°C. Thus, the asynchrony of temperature with light in the late winter and spring months presents a serious challenge for the seaweed farmer in Atlantic Canada. By contrast, very productive seaweed zones occur at high latitudes in Europe. Coastal waters in the Orkney and Shetland Islands region, and along the central coast of Norway, rarely

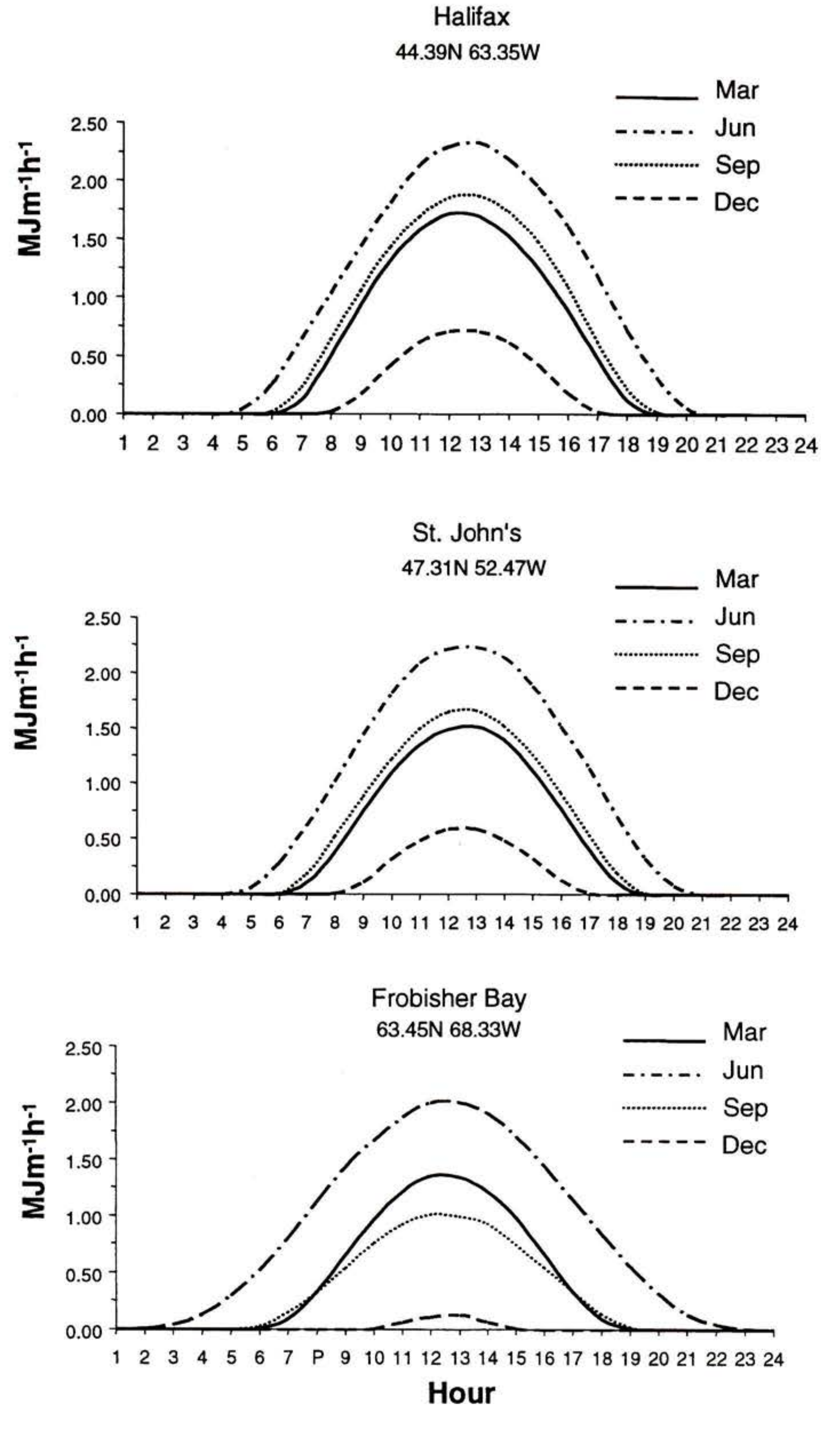

Figure 2. Average total solar radiation measured hourly at Halifax, St. John's, and Frobisher Bay.[16]

drop below 4 to 5°C in winter, a situation quite different from that pertaining in Atlantic Canada (cf. Fig. 3 in Rosenthal et al.[15]). Land-based culture systems in eastern Canada would seem to have an advantage over those located in adjacent coastal waters in that site layout can be planned to maximize solar heat input, or sources of waste heat may be utilized if such are available. In addition, ponds can be covered to create a greenhouse effect, thereby gaining the critical few degrees needed to dramatically improve photosynthetic conversion of the available light energy to seaweed biomass.

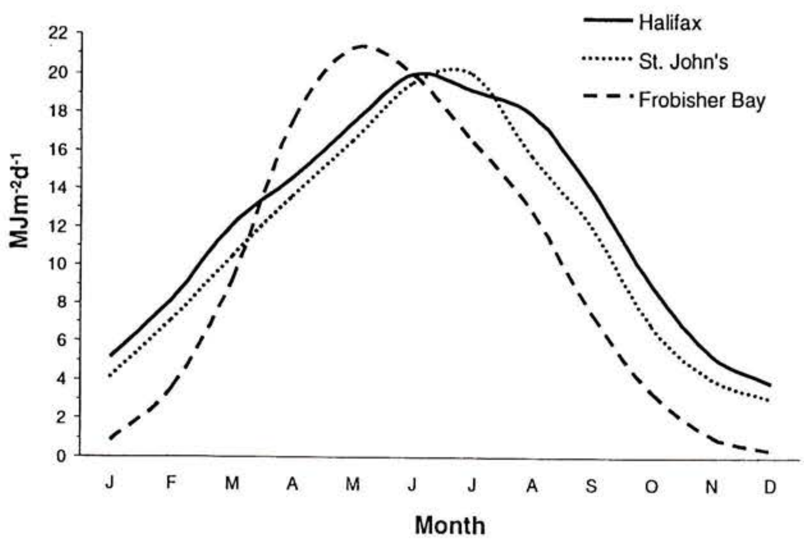

Figure 3. Average daily total solar radiation by month for Halifax, St. John's, and Frobisher Bay.[16]

Summary

Seaweed aquaculture in Atlantic Canada can be traced to the selection and growth of the T4 cultivar of Irish moss in 1970 at the Atlantic Regional Laboratory. Genu Canada and Marine Colloids, Inc. evaluated the new technology almost simultaneously, at various test sites in the Maritimes commencing in 1973. Three companies currently culture red seaweeds in Canada.

High seaweed productivity results from light energy being delivered within a temperature and nutrient regimen suitable for optimal seaweed growth. Sufficient natural light is available for this purpose in the early months of the year (March to May) in Atlantic Canada, but low coastal water temperatures during this period can result in suboptimal production.

I thank Andrew Bauder for plotting the graphs. Issued as NRCC no. 42297.

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Domestication of Nori for Northeast America: The Asian Experience

C. Yarish, T. Chopin, R. Wilkes, A.C. Mathieson, X.G. Fei and S. Lu

In view of the broad-based support of several federal agencies for enhanced mariculture of coastal resources, including the National and New England Sea Grant College Programs, Northeast Regional Aquaculture Center, Departments of Commerce and Agriculture, and the National Science Foundation, we have embarked upon a study of domesticating indigenous species of *Porphyra* for commercial cultivation. Nori cultivation has one of the greatest potentials for generating a viable seaweed mariculture industry in the United States and Canada. Detailed seasonal and spatial collections from diverse coastal and estuarine habitats have been made to delineate the seasonality and habitat preferences of *Porphyra* in coastal New England and the Canadian Maritime Provinces. At least seven different species of *Porphyra* are being examined using a variety of traditional morphometric parameters and cytological and molecular techniques. Over 130 unialgal cultures of *Porphyra amplissima, P. miniata, P. umbilicalis, P. linearis, P. purpurea, P. leucosticta*, and *P. carolinensis* have been established and are being maintained for comparative molecular genetic and ecophysiological investigations. The abilities of each of these isolates to respond to traditional Asian nori cultivation techniques are also under examination. Several strains of each of the species of *Porphyra* have successfully completed their life cycles in culture and F_2 individuals have been obtained for *P. amplissima, P. leucosticta, P. purpurea*, and *P. umbilicalis*. Conchocelis cultures have been successfully established in bivalve shells, a very important step in the domestication process. Whether or not nori aquaculture will ultimately succeed in New England and the Canadian Maritimes will depend in large part upon several key factors, including: (1) successful transfer and modification of Chinese and Japanese cultivation technologies to local coastal environments; (2) development of genetically improved strains (cultivars) of marketable nori that will extend the growing and harvest season; (3) establishing a constant and readily available supply of a "seedstock" of juvenile organisms; and (4) expansion of the area presently used for cultivation (i.e., beyond northern Maine).

Introduction

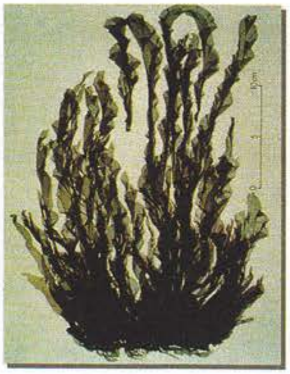
The red alga *Porphyra*, or nori as it is commonly called, is a major source of food for humans throughout the world and is the most valuable cultured seaweed in the world today. In 1992, approximately 15 billion sheets were produced,[1,2] with an annual value of over US$1.8 billion.[3] *Porphyra* is primarily used as the reddish-black wrapping around the Japanese delicacy "sushi", which consists of chopped, pressed, and toasted blades, plus rice and other ingredients. Nori is a major source of taurine, which controls blood cholesterol levels,[4] and is a staple in macrobiotic diets.[5] As well as being delicious, nori contains high levels of protein (25-50%), vitamins (higher vitamin C than in oranges), trace minerals, and dietary fiber.[6] It also serves as a preferred source of the red pigment r-phycoerythrin, which is utilized as a fluorescent "tag" in the medical diagnostic industry.[7]

Life Cycle and Cultivation of Nori in Asia

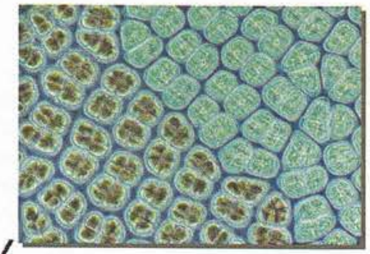
The farming of *Porphyra* was revolutionized in 1949 when Kathleen Drew discovered the diploid shell-boring conchocelis phase of *Porphyra* (Fig. 1). This helped to provide the Asian nori industry with a reliable source of seedstock. Conchocelis is now cul-

Porphyra life history

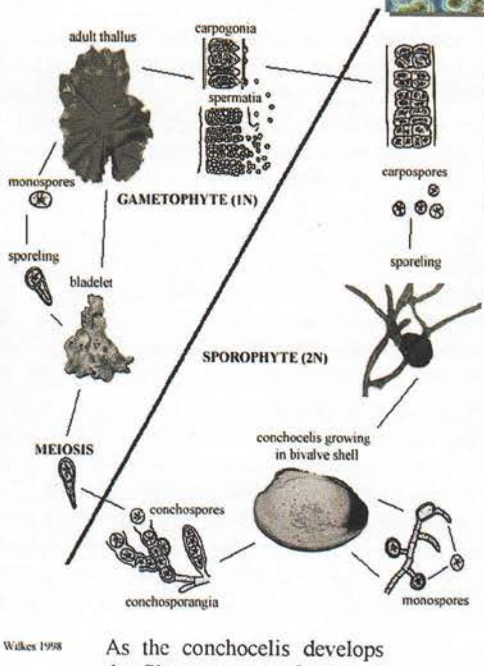
Porphyra yezoensis is the most commonly used species in commercial farming. The haploid blades germinate from conchospores released by the conchocelis-phase of the life history.



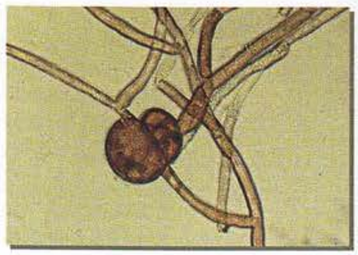
As the blades matures spermatangial and carpogonial tissue forms in patches towards the edges of the thallus



Meiosis occurs after spore release and the four products remain together after the spore germinates. The spore germinate to form small bladelets which eventually develop into the adult thallus



As the carpogonia are fertilised they release diploid carpospores. These spores settle on calcareous substrates and germinate to form the filamentous conchocelis-phase of the life-history



The conchocelis grows under the surface of the shell and can eventually cover the entire surface

As the conchocelis develops the filaments grow fatter and form conchosporangia. The conchospores are formed in these conchosporangia

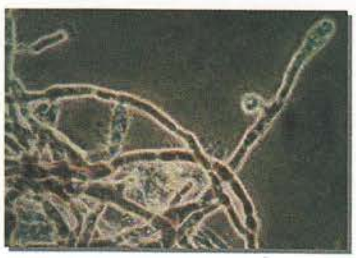


Figure 1. Life history of *Porphyra*. Note how the haploid blade generation alternates with the diploid filamentous shell-boring conchocelis generation.

tivated in calcareous shells in large quantities during late spring and summer (April to September). Spore release from the shells can be controlled, providing an abundant source of conchospores for the seeding of nets. Shells are kept in large tanks (either hung vertically or spread across the bottom) and by carefully controlling the temperature, mass conchospore release can be induced. Nets (1.8 x 18 m) are then coated with these conchospores and transferred to nursery culture. In nursery culture, the nets are put into the sea and carefully monitored for blade development. During this early stage, the nets are raised out of the water daily to inhibit fouling organisms. Various methods are used for supporting the nets and controlling the degree of exposure. Once blades reach 2 to 3 mm, the nets can be transferred to farm sites or frozen for later use. Nets that are to be frozen are initially air-dried to reduce the water content of *Porphyra* to 20 to 40%, and then stored at - 20°C. The nets can then be used to replace lost or damaged ones. Three basic types of nori culture are utilized to grow the blades until harvest: fixed-pole, semi-floating-raft, and floating-raft (Fig. 2). Nori is fast growing, requiring less than 40 days from seeding to first harvest, and can be repeatedly harvested every 9 to 15 days.[7,8]

Cultivation of Nori in Northeastern America

Previous attempts to culture nori on the west coast of the United States and Canada have been unsuccessful. The failure was not due to market size, economic viability of the participants, nor the biological aspects of cultivation, but solely on the inability of nori farmers to obtain aquaculture lease permits in the coastal waters of Washington State. Political pressure brought by riparian land owners and commercial fishermen was too much for the fledgling industry to overcome.[8] The political forces that resulted in the collapse of the Washington State effort have not been present in coastal New England and the Canadian Maritimes. In initiating a nori cultivation program in northeastern Maine (i.e., Cobscook Bay, Washington County), Coastal Plantations International received the support of local, state, and federal agencies, as well as popular interest. The development of a labor-intensive sea vegetable industry is expected to reduce the unemployment rate and reliance on a single dominant, but vulnerable, source of employment — salmon farming. The legislatures in Maine, Connecticut and other New England states have been overwhelmingly supportive of lease site acquisition, statute changes, and extension support.

With the lack of understanding of the biology of native New England nori species, Coastal Plantations International has primarily utilized a commercially-valuable Asiatic taxon, *Porphyra yezoensis*. It was developed during the 1960s by strain improvement programs on *P. tenera* and *P. yezoensis*.[9] Although *P. yezoensis* has many desirable features, it had been selected for conditions in northern Japan and is having serious difficulty dealing with northeastern Maine's coastal environments. Therefore, it was logical to establish a cultivar improvement program for local *Porphyra* species, just as has been done in Japan. Through such a program, genetically improved nori

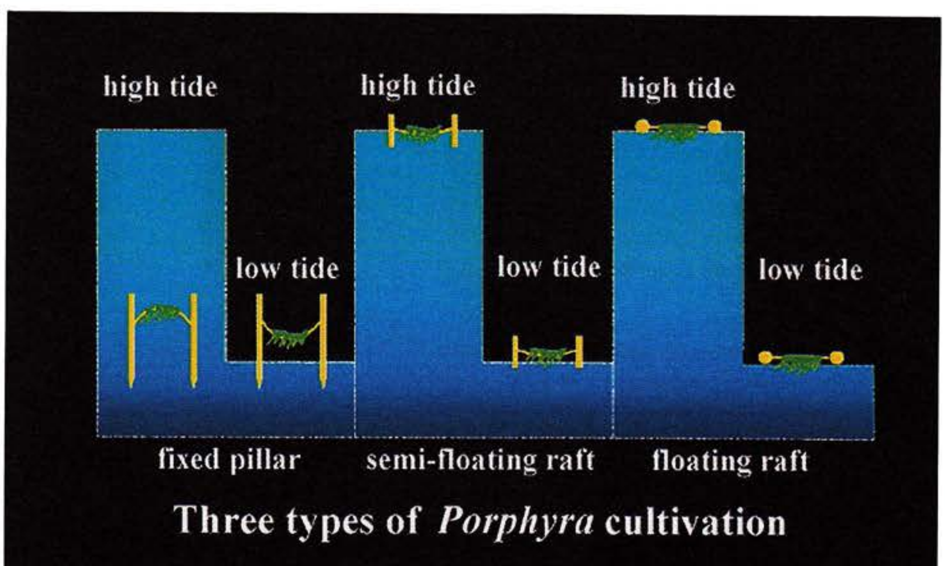


Figure 2. Three basic types of *Porphyra* culture systems: fixed pole, semi-floating raft and floating raft (after IOEP[23]).

cultivars are being developed, primarily with the support of the National and New England Sea Grant College Programs. The cultivars should be better adapted to local conditions than *P. yezoensis*.

Our research program is coordinating a field and culture assessment of "native" northwest Atlantic *Porphyra* species from Long Island Sound to the Canadian Maritime Provinces. It is primarily attempting to clarify the taxonomic status, the physiological requirements, and the potential value of indigenous species of nori for food, eutrophication abatement, and biochemical components.[10-12]

Indigenous Nori Species in Northeastern America

At least seven species of native *Porphyra*'s occur in New England and the Maritime Provinces of Canada, including *Porphyra amplissima* (Kjellman) Setchell & Hus in Hus, *P. miniata* (C. Agardh) C. Agardh, *P. umbilicalis* (Linnaeus) J. Agardh, *P. linearis* Greville, *P. purpurea* (Roth) C. Agardh, *P. leucosticta* Thuret in Le Jolis, and *P. carolinensis* Coll et Cox.[13-17] Presently we are characterizing the species composition and seasonality of each of these taxa within Long Island Sound and New England's coastal and estuarine habitats.[18,19] *Porphyra umbilicalis* is by far the most abundant species, spatially and temporally, within the Gulf of Maine and Long Island Sound. It occurs throughout the year within the eulittoral zone. *Porphyra amplissima* is most abundant within the northern Gulf of Maine, particularly occurring during the spring and summer within coastal and disjunct estuarine locales. It is most abundant within the low intertidal and subtidal zones and appears in the southern Gulf of Maine. *Porphyra linearis* forms localized ephemeral populations within the upper intertidal zones of open coastal habitats. It occurs in the winter along coastal Atlantic Canada, within the Gulf of Maine, and extends as far south as eastern Long Island Sound. Young fronds of *Porphyra leucosticta* are initiated in early winter. Typically, it grows epiphytically on fronds of *Chondrus crispus*, *Fucus vesiculosus*, and on the hemiparasitic red alga *Polysiphonia lanosa*, and extends from the Gulf of Maine southward to Long Island Sound. As the winter progresses, it may be found epiphytically on other algae and occasionally on rocks within the lower eulittoral and into the upper sublittoral zones. By early summer, the leafy thalli disappear in eulittoral habitats, but may persist subtidally. Limited knowledge is available about the phenology of *P. miniata* and *P. purpurea*. The latter is enigmatic in its distribution, with initial reports of it occurring only in the Canadian Maritimes. However, we have found the taxa as far south as Long Island Sound throughout the summer. Plants in the northern part of its range are common throughout the year in coastal habitats, with populations in the Bay of Fundy and the Minas Basin being most common in late autumn and early winter. There appears to be distinct genetic differences between northern and southern populations, as the Long Island Sound populations are only found during the summer months. Recently, we have found *P. carolinensis* growing epilithically in eastern Long Island Sound in late autumn. This appears to be the northern limit of this taxon in the northeastern United States.

Physiological Experiments

Physiological studies have shown that temperature and daylength play a key role in controlling the development of the conchocelis.[20,21] Using a crossed-gradient light intensity-temperature culture system,

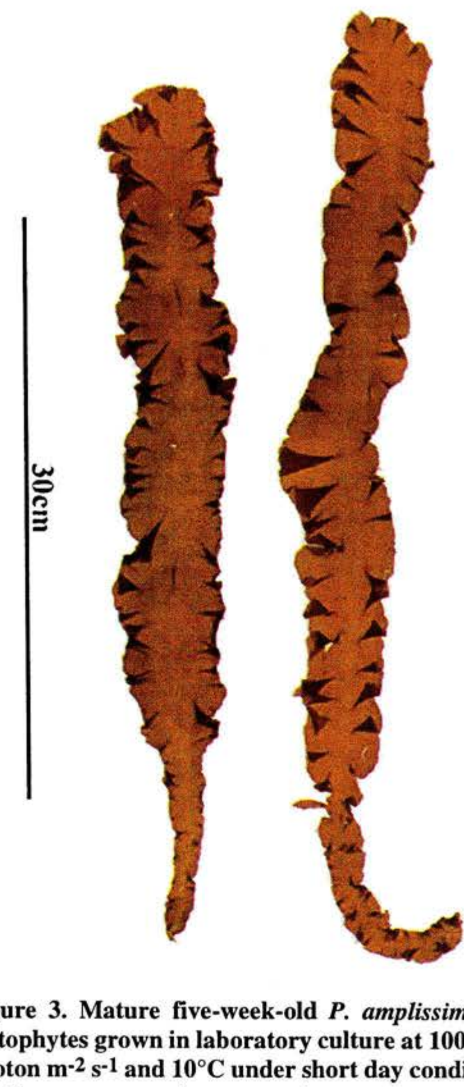


Figure 3. Mature five-week-old *P. amplissima* gametophytes grown in laboratory culture at 100 µmol photon m^{-2} s^{-1} and 10°C under short day conditions. Thallus was grown from a conchospore.

the environmental tolerances of different local species are being investigated to determine the optimum conditions for growth and reproductive development of different species.[22] Conditions for vegetative conchocelis growth of *P. amplissima* are 5 to 100 μmol photon m^{-2} s^{-1} and 5 to 15°C, while its upper lethal temperature is 17°C. Conditions for conchosporangium induction and conchospore maturation are 5 to 25 μmol photon m^{-2} s^{-1} at 5° to 15°C after 2 to 4 weeks. Sexual maturity of the leafy gametophytes of *P. amplissima* occurs after approximately 5 weeks at 100 μmol photon m^{-2} s^{-1} and 10°C under short-day conditions (Fig. 3). Optimal conditions for vegetative conchocelis growth of *P. leucosticta* is from 10 to 40 μmol photon m^{-2} s^{-1} and 10 to 20°C (Fig. 4a). Its upper lethal temperatures are 20° to 25°C. Optimal temperature and daylength conditions for conchosporangium development are 10 to 20 μmol photon m^{-2} s^{-1}, at 10 to 15°C (Fig. 4b). Monospore production by an asexually reproducing *P. leucosticta* is from 10 to 100 μmol photon m^{-2} s^{-1} and 5° to 20°C, with an optimum at 10° to 15°C under short days. Optimal conditions for vegetative conchocelis growth of *P. purpurea* is from 10 to 40 μmol photon m^{-2} s^{-1} and 10° to 15°C (Fig. 4c). It has an upper lethal temperature of 20° to 25°C. Optimal temperature and daylength conditions for conchosporangium development by *P. purpurea* are 10 to 20 μmol photon m^{-2} s^{-1} at 10° to 15°C (Fig. 4d). Optimal vegetative conchocelis growth of *P. purpurea* from northern populations (e.g. New Brunswick) have a temperature optimum of 10°C, whereas the southern populations (Long Island Sound) have an optimum of 15°C at long days. The former populations have an upper lethal temperature of 20°C, whereas the southern populations continue to grow above that temperature.

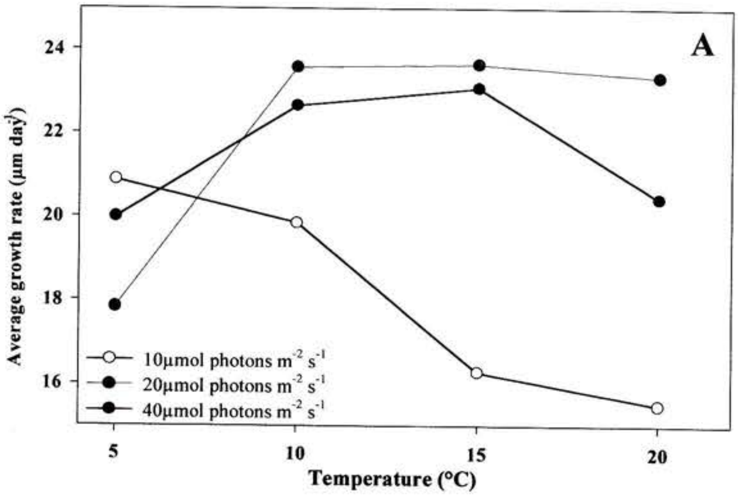


Figure 4a. Mean growth rates of *P. leucosticta* conchocelis grown at four different temperatures and three light intensities at day-neutral

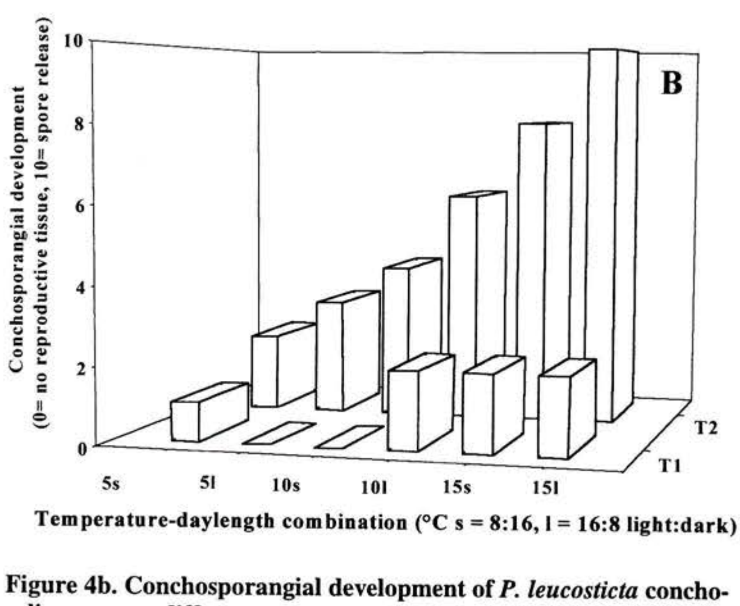


Figure 4b. Conchosporangial development of *P. leucosticta* conchocelis grown at different temperatures and daylengths.

Experimental Domestication Studies

Current nori farming technology relies on conchocelis growing in bivalve shells to produce conchospores to seed nets. We are in the process of moving to experimental commercial cultivation with clam shells (*Mercenaria mercenaria*) that have been inoculated with conchocelis of *P. amplissima*, *P. leucosticta* and *P. purpurea* (Fig. 1). We still need to control the development of the conchocelis, conchospore formation, and release from these shells. For these taxa, this is significant, since it is the first time that successful cultures have been cycled to produce thalli via conchocelis "seeded" shells.

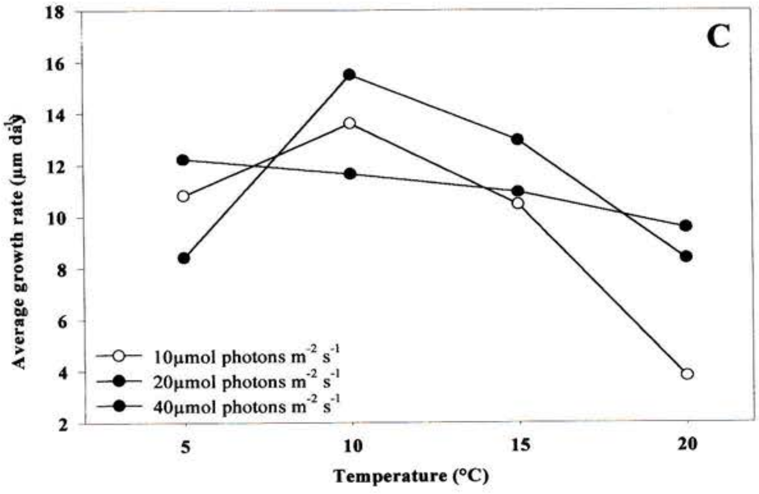


Figure 4c. Mean growth rates of *P. purpurea* conchocelis grown at four different temperatures and three light intensities at day- neutral conditions.

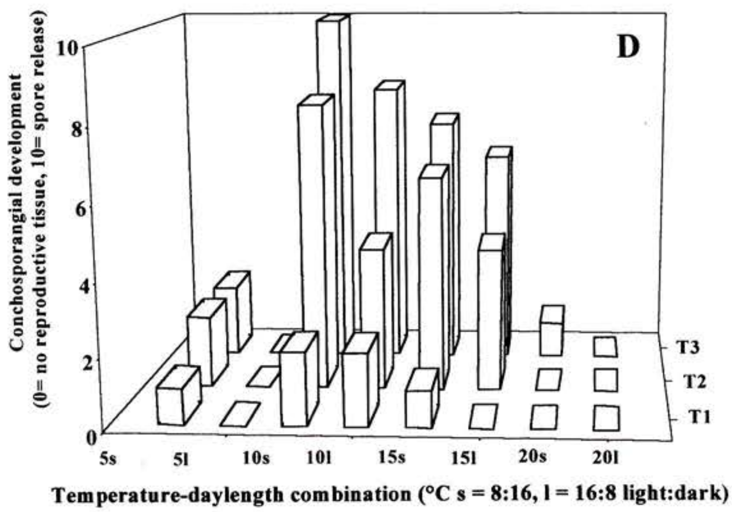


Figure 4d. Conchosporangial development of *P. purpurea* conchocelis grown at different temperatures and daylengths.

Conclusions

In view of the broad-based support of several federal agencies for enhanced mariculture of coastal resources, *Porphyra* cultivation in northeastern America has one of the greatest potentials for generating a viable seaweed culture industry in New England and the Canadian Maritime Provinces. Preliminary studies suggest that four "native" *Porphyra* taxa (*P. amplissima*, *P. linearis*, *P. purpurea*, and *P. leucosticta*) may be of marketable quality for "sushi," as well as a variety of industrial and biotechnological applications, including eutrophication abatement (i.e., bioremediation).[7,11,12] With federal and state assistance, we have established an extensive nori culture collection and cultivar improvement program for local *Porphyra* species. We hope that by gaining better knowledge of the ecological requirements of these native species, viable commercially entities can be identified. Through such a program, genetically improved nori cultivars will be developed, just as has been done in Japan. Ultimately, the most promising plants (i.e., ones that have the most advantageous shapes, taste, appropriate maturation periods for particular sites, sufficient monospore production, and unique pigment composition) will be made available for "grow-out" at Coastal Plantation International's facility in Eastport, Maine.

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Potential for a New Seaweed Industry in Canada: A Western Perspective

Louis D. Druehl

New trends in fishery production and aquaculture have given rise to increased demands for seaweed products. Earlier, on Canada's west coast, kelp for sea vegetables, sea urchin feed, and the herring-roe-on-kelp (HROK) fishery was totally derived from wild stock. Now, commercial kelp farms help meet the demands for sea urchin feed and sea vegetable and pharmaceutical production. Also, test farms are evaluating the application of cultivated kelp for the HROK fishery. New products requiring seaweeds are in various stages of becoming established. These include kelp as an additive in manufactured fish feeds and as material for the extraction of pharmaceutical and cosmetic chemicals and the production of fertilizers and pesticides for organic farmers. The technologies of kelp seed production and kelp farm construction and operation are well established for a variety of Canadian kelp species.

Introduction

In the past, seaweeds were considered specialty products for a minority of North Americans. Stores catering to Asians sold the red alga *Porphyra* under the Japanese name nori and various kelp species under the names kombu, wakame (Japanese), and hadai (Chinese). On the east coast of North America, dulse was locally marketed as a chip. Health food stores also carried some of these products and kelp pills were usually sold as well. Using seaweeds as fertilizer was an informal exercise, usually restricted to gardeners living near the sea shore. On the west coast, native peoples harvested herring roe attached to seaweed and other substrates. This was used as food for special feasts and in trade with inland native groups.

In the last 20 years in North America, there has been an explosion of new seaweed products and local acceptance of such products. The technology to farm seaweeds for commercial purposes has also been developed for some species. The following sections describe some of the new product lines and the motivation behind them. Further, the status of Canadian kelp farming technology will be discussed. The views presented here reflect to a large extent my involvement with the seaweed industry over the past 20 years. My expertise is mostly restricted to kelp (Laminariales) and has focused on the west coast. Appendix I lists projects recently undertaken by Canadian Kelp Resources Ltd.

Seaweed Products

Sea vegetables

In addition to traditional Japanese kelp products and nori, there is a growing list of North American seaweed products aimed at American and Canadian consumers. Presently, about six companies (mostly small) service and compete for local markets. I suspect all of these companies are currently experiencing substantially increased sales. This market growth reflects the greater exposure of North Americans to seaweed products that has resulted from the advent of sushi shops, western-oriented sea-vegetable cookbooks, and increasing awareness of seaweed products and suggestions of related health benefits (see section on pharmaceuticals below).

Sea vegetable products include whole-dried, fresh, and fresh-frozen plants, and flaked, powered, and floured dried material. The condiments are mixed with other spices or used "pure". The final sea vegetable product may be a tea, soup mix, general seasoning, or a vegetable for use in stir-fry or chowder. A new line to be considered is expensive and healthy "junk foods". Flavored kelp chips may have a substantial market niche. For example, Kelp Farm, on the Isle of Man, produces a variety of "Kelp Crunchies". Similarly, the market for dulse could be expanded.

The Asian market, which has a huge appetite for sea vegetables, has not been a major factor in the growth of North American kelp-derived sea vegetables. This is probably the result of restrictive Japanese import practices and the tradition of associating the best quality with domestic products. However, in the future, there may be Japanese demand for North American kelp, due to the increasing population and loss of suitable cultivation and wild harvest sites in Japan.[1]

The Japanese gift market presents an opportunity for North American sea vegetable products. The value of this market, however, varies with fluctuations in the number of Japanese tourists visiting North America. According to Bracey,[2] a Japanese tourist will purchase 5 to 15 identical gifts in the $10 to $15 range. In 1989 this market was worth $125 million in Canada. The ideal gift is food that is clearly of Canadian origin, lightweight and nonperishable. Packaging is very important and recommended outlets are airport and hotel gift shops. A drawback is that demand for products is trendy and interest in a particular item can quickly wane.

Pharmaceuticals

The general public is becoming increasingly aware of the potential health benefits associated with kelp. This perception is supported by research. Riou et al.[3] reported on anti-tumor effects of a fucan (sulfated polysaccharide) extracted from *Ascophyllum nodosum* and concluded the product "is a very potent anti-tumor agent in cancer therapy". Chui and Fung[4] demonstrated the hypotensive effects (lowers blood pressure) of kelp (*Laminaria japonica*) in rats. Mauray et al.[5] documented anti-thrombotic and anticoagulant activities of fucodan from *Ascophyllum nodosum* and noted that this compound "shows promise as an anti-thrombotic drug" (anti-stroke). Stirk et al.[6] demonstrated inhibition of prostaglandin synthesis (anti-inflammatory activity) by extracts of several South African seaweeds.

These and other studies suggest seaweeds, particularly brown algae, may prove to be sources of valuable pharmaceuticals. All of the above studies were conducted on rodents or human tissue in culture. However, much work needs to be done to identify the active constituents and extensively test them. Presently, pills made from brown algal powders are the major seaweed pharmaceutical on the market. These contain a healthy array of micro-nutrients and, hopefully, are free of high levels of lead, chromium, and other toxic materials.

It is my opinion that the present increase in sea vegetable sales reflects to a significant degree an awareness by the general public of the potential health benefits. Future opportunities may result from our ability to cultivate and environmentally manipulate seaweeds which produce pharmaceuticals.

Cosmetics

The use of seaweeds as cosmetic aids or sources of cosmetically-active compounds is a growing area of interest. Brown algae (usually *Laminaria* or *Ascophyllum*) are commonly used in the manufacture of beauty aids (see de Roeck-Holtzhauer[7] for extended discussion). Seaweed and seaweed extracts used in skin care are often associated with thalassotherapy, which involves elements of the sea, including seaweeds, and has a long tradition in European spas. Traditionally, this therapy was used to cure a wide variety of ailments; today the emphasis is on feeling good and skin care. The seaweed is used in mud baths or body wraps, where it helps exfoliate dead skin, thereby rejuvenating the bather.

The use of seaweeds is a small but essential part of the spa industry. The isolated value of the seaweed is relatively low, but considerable value is added, primarily through ancillary spa service. Opportunities exist in supplying quality seaweed to local spas, particularly in some form of partnership.

Fertilizers and pesticides

Seaweeds, mainly kelp, harvested from the sea or off the beach are treated (powdered and extracted) and sold as fertilizers to be sprayed or mixed with soil. Claims suggest these seaweed materials may promote plant health by providing growth regulators and pesticidal components, as well as supplying nutrients. When subjected to scientific scrutiny, the claims have not always been substantiated.[8,9] Some claims, however, are valid and the users are convinced of the product's worth.

The increasing demand for organically-grown fruits and vegetables has driven producers to seek new ways to fertilize the soil, control pests, and regulate plant production while meeting the requirements of certified organic farming. Further, the realization that decades of farming have depleted important micronutrients (nutrients other than N-P-K) from soils has led farmers to use micronutrient-rich seaweeds to refurbish soils.

Companies on Canada's east and west coasts are presently responding to the burgeoning demand for seaweed-based fertilizers. I expect this industry will continue to grow to meet both domestic and offshore demands.

Fish food

A new fish food production system which combines kelp and fish offal as major ingredients is being tested in Japan and considered for the Prince Rupert area of British Columbia.[10] The European-developed system, called the Alfa Laval ConKix Fish Meal and Oil

Plant, is claimed to produce highly nutritive fish meal and oil with minimal damage to the nutrient value. The systems are small and target local fish processing factories. Although the specifics of this process have not been released, I assume the kelp is used as a binding agent, a source of pigments to enhance fish flesh color, and a possible source of minerals and some vitamins. Should this system prove viable, it is possible that a significant market niche for kelp would open.

Sea urchin feed

Sea urchin roe is a valuable fishery in British Columbia. In 1996, red sea urchins (whole animals) were selling for up to $3.30 per kilogram (average of $1.78/kg and total landed value of $11 million). Much of the wild harvest, in British Columbia and elsewhere, is stressed and there is a strong move to cultivate animals. In British Columbia, two culture models are being pursued: 1) tank rearing through the entire life cycle, and 2) field ranching of natural populations. Tank rearing requires feeding the animals through their entire growth period and ranching is based on fattening the animals (or rather their roe) for a few months prior to their harvest.

The animals considered for ranching in British Columbia exist in algal barrens where natural food is very limiting. Although the sea urchin population manages to support itself, the roe is poor quality. A study conducted by Canadian Kelp Resources Ltd. with the Huu-Ay-Aht First Nations indicated that a one-acre kelp farm could feed 44 000 sea urchins, of which 13 000 are of harvestable size, for one month prior to the roe harvest. The estimated maximum value added to the harvested roe due to increased quality was 145% or $16 200. In addition to this, there is the advantage of having strengthened 31 000 undersized sea urchins for future harvests. A test feeding of sea urchins from the algal barrens with farmed kelp has demonstrated the logistical feasibility of this approach.

Presently, there is a strong push to develop cost-effective artificial diets for sea urchin culture.[11] Kelp is a major natural food source of cold-water sea urchins. Farmed kelp allows the sea urchin fisher protracted seasonal access to feed and an easy way to handle the seaweed during feeding. Presently, artificial feeds sell for US$1000 per metric ton, but the hope is to lower this to between US$400 to $600 per metric ton.[11]

The role of kelp in this very strong fishery may take the form of an ingredient in artificial diets, a manipulated farmed food, or an enhanced wild food. From my perspective, kelp should always be considered the optimal food. In today's markets, it is easier to argue in favor of a natural feed over an artificial feed. Also, it may be cost effective. A recent study[12] has shown that sea urchins fed to satiation with prepared feed or kelp had similar roe production.

Presently, there is one commercial kelp farm in British Columbia supporting a commercial sea urchin rearing facility.

Herring-roe-on-kelp

In British Columbia, the herring-roe-on-kelp (HROK) fishery is shared by 30 to 40 license holders and is worth approximately $20 million dollars. This fishery involves bringing together quality herring and kelp (*Macrocystis*) in an enclosure. Often, the enclosure is located distant from a source of quality kelp and the kelp must be transported. Kelp that is excessively handled loses its ability to adhere to the herring roe, thus resulting in an inferior product. Farming may resolve some of the problems by providing kelp in the vicinity of the herring pens. Also, through selection, superior kelp may be provided to this fishery. British Columbia *Macrocystis* has been sold for up to $3.70 per fresh kilogram for this fishery.

Herring roe on other seaweeds

Herring roe is harvested on rockweed (*Fucus*) and *Laminaria*. However, the Japanese do not find these as attractive as the herring roe on *Macrocystis*. In the case of the rockweed, the substrate is tough. In the case of *Laminaria*, the problem may be the weaker adherence of the roe to the substrate. Many other Canadian kelp species including some *Laminaria* species have not been properly assessed as suitable substrates for herring roe. Should any of the available kelp species prove satisfactory, the product would be in direct competition with the established *Macrocystis*/roe fishery. Perhaps a more profitable tact would be to produce a herring roe/seaweed product that caters to a different market niche.

Kelp Farming

Kelp cultivation was initiated in British Columbia in the early 1980s.[13] The technology driving this cultivation was introduced from Japan and modified to fit local conditions and recent advances in our understanding of kelp biology.[14]

The basic farm unit in British Columbia consists of an anchored 40 x 70 m rope rectangle suspended 2 m below the surface. This frame, which is divided lengthwise into two equal rectangles, supports sixty 20-m long support ropes. These ropes are seeded with laboratory-produced kelp seed (actually, young plants about 4 mm long). Production by this system in Canada and elsewhere ranges from 3 to 28 wet kilograms per meter of rope for various species of *Laminaria*, or 3.6 to 33.6 metric tons per unit.[14]

Presently, there are two kelp farms of the type described above operating in British Columbia: one in support of kelp production for homeopathic pharmaceuticals and the other in support of a sea urchin feeding operation. In addition, there are four test farms in support of the herring-roe-on-kelp fishery. These test farms are designed to hold the plants at a constant distance from the ocean bottom, but below the surface. The following species have been successfully cultivated in British Columbia: *Laminaria saccharina*, *Laminaria groenlandica*, *Nereocystis leutkeana*, and *Macrocystis integrifolia*. Attempts to farm *Alaria marginata* have been unsuccessful due to severe grazing by a small crustacean.

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Canadian Kelp Resources produces and markets a variety of sea vegetables, from farmed and wild harvest, which are sold under the labels Canadian Kelp and Barkley Sound Kelp. This exercise gives us considerable practical experience in developing economic seaweed systems from the "beach to the shelf" and introduces us to established and emerging markets.

Appendix I

Canadian Kelp Resources Ltd. is a small company involved in assisting others assess their seaweed resources, designing seaweed products and establishing kelp farms. Following are some of our ongoing and recently completed projects and workshops.

Projects

1997 to 1998 — Established four giant kelp (*Macrocystis*) test farms in support of Tsimshian Tribal Council HROK J Licenses in the vicinity of Prince Rupert, BC.

1995 to 1998 — Custom culture of selected kelp for homeopathic products for VitaKelp, Vancouver.

1997 — Assessed seaweed resources and identified potential kelp products for native Aleuts on the Commander Islands, Russia, in conjunction with The AMIQ Institute of Russia.

1997 — Initiated search for alternative seaweed species for the herring roe-on-kelp fishery with Canadian Benthic Ltd., Bamfield, BC.

1997 — Produced kelp "seed" for IEC Collaborative Marine R&D, Thorpe Island, BC.

1997 — Evaluated feeding "ranched" sea urchins farmed kelp with Huu ay aht, Bamfield, BC.

1993 to 1996 — Conducted seaweed surveys, assessed harvesting impact, tested long-line kelp farming, help design marketable kelp products and tested the feasibility of using kelp as an energy resource for Kivalliq Land & Sea Resources, Whale Cove, NWT. This comprehensive project defined high value-added products requiring considerable local labour that will enhance the local economy, but result in minimal environmental impact.

1995 — Explored the possibility of using BC *Macrocystis* in the herring-roe-on-kelp fishery in New Brunswick for Ocean Star Seafoods Inc., Bellingham, WA.

1995 to 1994 — Identified seaweed sources of potential exotic chemicals for Phillip Rockley Ltd., New York. These chemicals were for pharmaceutical and cosmetic firms.

1994 — Produced *Macrocystis* and *Nereocystis* (bull kelp) seed for Kwakuitl Tribal Council, Fort Rupert, BC. This seed was for test farms to support the herring-roe-on-kelp fishery and explore new marketable kelp products.

1994 — Produced *Nereocystis* seed for Island Scallop Ltd., Qualicum, BC. They operated a test farm to explore Japanese sea vegetable production.

Workshops

1998 — Kelp product production workshop for native Aleut from the Commander Islands, Russia, in conjunction with The AMIQ Institute in Bamfield.

1998 — Kelp cultivation workshop for Tsimshian Tribal Council held in Bamfield.

1997 — Kelp product identification workshops for Haida and Tsimshian First Nations held in Skidegate and Prince Rupert.

1997 — Kelp potential and uses workshop for Tsimshian Tribal Council, Council of Haida Nation and Heiltsuk Tribal Council with the Northwest Maritime Institute, Prince Rupert.

1996 — Workshop on marine resource management techniques (3 weeks) and workshop on sustainable marine resource opportunities (1 week) held in Bamfield for Kivalliq Land & Sea Resources, Whale Cove, NWT.

1996 — Seaweed product identification and production workshop held in Bamfield for Kawaki (Canada) Ltd., Richmond BC.

1996 — Workshop on kelp farming and feeding strategies applicable to abalone farming held in Bamfield for Ethelda Bay Ventures Inc., Prince Rupert, BC.

1996 — Kwakiutl youth vocational opportunities fair held in Campbell River for the Kwakiutl District Council, Campbell River, BC.

1995 — Workshop on kelp seed production methods and kelp farming held in Bamfield for the Tsimshian Tribal Council, Prince Rupert, BC.

1995 — Workshop on seaweed standing crop and harvesting assessment methods held in Whale Cove for Kivalliq Land & Sea Resources, Whale Cove, NWT.

1994 — Workshop on kelp seed production methods held in Bamfield for the Kwakiutl Tribal Council, Fort Rupert, BC.

1994 — From the beach to the shelf — a workshop dealing with processing, packaging, labeling, bar codes, etc., held in Bamfield for Kivalliq Land & Sea Resources, Whale Cove, NWT.

1992 — Workshop on the conservation biology of seaweeds held in Prince Rupert for the Tsimshian Tribal Council, Prince Rupert, BC.

Developing Seaweed Aquaculture in the Northeastern United States and Canada: Species Selection and Strain Improvement

Donald P. Cheney

The seaweed industry of the northeastern United States and Canada has always been based upon the harvest of wild plants. Future growth of this industry, however, will likely depend upon developing aquaculture systems of one or more seaweeds that produce high-value specialty products that cannot be obtained from wild plants. The purpose of this paper is to identify the three red algal species with the best potential for seaweed cultivation in the northeastern United States and Canada (*Chondrus crispus, Palmaria palmata* and *Porphyra yezoensis)* and to describe how genetic modification and strain improvement can contribute to the success of each. As in agriculture, the success of an aquaculture project often depends as much upon the suitability of the species or strain being cultured as anything else. A species' suitability can be improved by modifying, for example, its growth rate, product yield, or temperature tolerance. Such improvements can now be made to all of the above species using modern biotechnological techniques.

Introduction

The seaweed industry has a long history in the northeastern United States and Canada. It was here that the carrageenan industry had its roots. The harvest of *Chondrus crispus* (Irish moss) provided most of the raw materials for the carrageenan industry from its origin to the early 1980s. Unfortunately the seaweed industry in this region is currently just a fraction of what it used to be. Use of *Chondrus crispus*, for example, has been replaced by a cheaper source of raw material that is farmed in less developed, tropical countries. Today the the largest commercial seaweed industry in our region is probably the harvest of the brown seaweed *Ascophyllum nodosum* in southern Nova Scotia by Acadian Seaplants Ltd. for the production of liquid fertilizer. Acadian Seaplants Ltd. also grows a small amount of *Chondrus crispus* in ponds for a Japanese food market. Other commercial seaweed activity includes the wild harvest of a variety of seaweeds for the health food market by Maine Coast Sea Vegetables and the recently initiated commercial farming of *Porphyra* by Coastal Plantations International.(1)

Can anything be done to expand the seaweed industry in the northeastern United States and Canada? I think so. However, I do not think significant commercial growth can occur in the region if the industry relies on the harvest of wild plants. For growth to occur, the industry must be competitive with other regions where seaweeds can be farmed more inexpensively and/or more efficiently. To be competitive, the industry must develop aquaculture systems for one or more seaweeds that produce high-value specialty products and not low-priced commodity products.

The purpose of this paper is to describe the top three candidate species of red algae for seaweed cultivation in this region and to briefly describe how genetic modification and strain improvement can contribute to the commercial success of each.

Critical Factors for the Success of a New Aquaculture Program

Developing a successful new aquaculture project is an extremely difficult endeavor — one more likely to fail than succeed. However, the prospects for success can be increased if the following three critical factors are met: 1) proper species selection; 2) availability of suitable cultivation technology; and 3) capability for strain improvement. Clearly, the single most important factor in developing a new aquaculture project is species selection. Not only should the species be selected on the basis of its capability of being cultivated, but it should also have a market value that clearly justifies its cultivation. When considering market value,

Table 1. Top candidate species for seaweed aquaculture in the northeastern United States and Canada.

Species	Uses
1. *Porphyra* (Nori)	widely eaten; valuable pigments; potential source of EPA
2. *Chondrus crispus* (Irish moss)	produces *kappa* and *lambda* carrageenan
3. *Palmaria palmata* (Dulse)	eaten as health food; potential source of EPA

the size of a product's market should be taken into account, not just its price. Production of a high-valued product does not alone justify cultivation, especially if the market is small or a comparable product is available from a more cheaply harvested wild plant.

The second factor to consider in selecting a species is its capability for aquaculture. Ideally, it is best if a cultivation technology has already been developed for the species selected, or for a closely related species. Fortunately, there has been a considerable degree of success in cultivating seaweeds in our region, both in the past (see Mathieson[2] and Yarish et al.[3]) and present.[1] Therefore, I believe that the technology necessary for expanding seaweed aquaculture in our region already exists. What is crucial is the choice of one or more suitable species.

Finally, taking a lesson from agriculture, an aquaculture project's economic success will often depend upon maximizing the suitability of the strain being cultured as much as anything else. Species suitability can be increased through strain improvement. Therefore, any new aquaculture project should include the capability to develop new strains through a genetic modification or strain improvement program. Strain improvement can make a critical difference in the economic success of an aquaculture project by improving, for example, growth rate, product yield, and temperature tolerance. Using modern biotechnological techniques such as protoplast fusion (Figure 1), we can make modifications in seaweeds today that would have been previously impossible, including those just listed (e.g., Cheney et al.[3]).

Top Candidate Species for Seaweed Aquaculture

I believe the top candidate species for seaweed aquaculture in the northeastern United States and Canada belong to the red and brown algae. The brown seaweed with probably the most promising potential is *Laminaria* (*Laminaria* aquaculture is discussed in another contribution in this volume[4]). The red seaweeds with the greatest potential for aquaculture success in our region are: *Chondrus crispus*, *Palmaria palmata* and *Porphyra yezoensis*. Each of these seaweeds produces or could produce one or more high-value products and has already been cultivated on a commercial or experimental scale (Table 1).

Chondrus crispus

Chondrus crispus is an attractive candidate for aquaculture because of its ability to produce three types of carrageenan and its proven capability to be cultivated in tanks and ponds in southern Nova Scotia and Massachusetts.[6,7] The alternating life history phases of *Chondrus* produce different types of carrageenan in their cell walls, with haploid gametophytes producing primarily *kappa* carrageenan (plus a small amount of *iota* carrageenan) and diploid sporophytes producing *lambda* carrageenan. These three carrageenans differ in the amounts and position of ester sulfate groups on their polysaccharide chain, which in turn cause very different gelling properties.

Historically, *Chondrus crispus* was the single most important source of *kappa* carrageenan in the world. Today, *kappa* carrageenan from *C. crispus* has been replaced for most (but not all) food applications by *kappa* carrageenan from the tropical seaweed *Kappaphycus alvarezii* (=*Euchuema cottonii*), which is farmed extensively in the Philippines and Indonesia. While *C. crispus* is still used as a source for what is termed "soft-*kappa*" and *lambda* carrageenan, the markets for both are relatively small.

In recent years, the carrageenan industry has concentrated on developing stable sources of its raw material through cultivation. Most of this cultivation has taken place in less-developed, tropical countries where labor costs are low and seaweeds can be farmed more or less year-round. Expansion of the carrageenan industry has been stable but slow. Future growth depends at least in part upon the development of new and different carrageenan compositions with new potential applications. One approach to obtaining new types of carrageenans is to introduce new functional properties into a species already capable of being cultivated. We have attempted to demonstrate the feasibility of this approach by producing new strains of

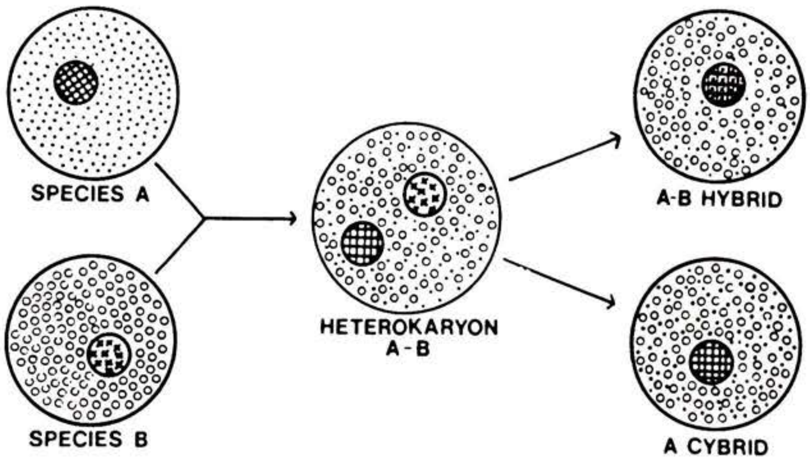

Figure 1. Diagram of protoplast fusion and its potential products, which include A-B hybrids, A or B cybrids that contain the nucleus of one parent and a mixture of cytoplasmic organelles, and A-A or B-B polyploids (not shown).

Chondrus crispus with novel carrageenan compositions.

New strains of *Chondrus crispus* are produced using a special, patented form of protoplast fusion called "spore-protoplast fusion".[8] Using this technique, we have successfully fused protoplasts of the different life history phases of *Chondrus* in all possible combinations. That is, we have fused n & n, n & 2n, and 2n & 2n protoplasts. While this work is still in progress, we have already identified one plant (#7/12-1), produced from an n & 2n fusion experiment, that appears to produce a carrageenan of novel composition. Specifically, it exhibits a reduced level of 3,6-anhydrogalactose-$2SO_4$ and a lower gel strength.[9-11] It also has a DNA level that is intermediate between that of haploid and diploid *C. crispus* plants.[12] We have also produced *Chondrus* plants with a higher temperature limit through mutagenesis and repeated selection of tissue cultures.[9]

Palmaria spp.

Palmaria palmata (= *Rhodymenia palmata*), popularly known as "dulse", has been harvested for decades from the Maritime Provinces, especially from Grand Manan, New Brunswick. It is typically collected by hand, dried, and sold as a health food. It contains as much as 35% protein and is a rich source of vitamins and eicosapentaenoic acid (EPA).[13,14] EPA is an omega-3 fatty acid that is thought to have a number of health benefits, including preventing blood platelet aggregation and reducing blood cholesterol levels in adult diets, as well as improving brain cell development in infants.

Based on culture experiments conducted at the National Research Council of Canada in the 1980s (e.g., Morgan et al.[15]), it appears that *Palmaria* can be cultured in tank or pond culture systems similar to those used for *Chondrus*. In fact, a Pacific coast species of *Palmaria*, *P. mollis*, is apparently already being cultured in ponds as a food for abalone.[16] In order to develop a *Palmaria* aquaculture system in our region, I would recommend that a strain be developed with a morphology specifically adapted for tank or pond culture and with the capability of being cultured indefinitely without becoming reproductive. One approach to accomplishing this would be to use spore-protoplast fusion to produce sterile, fast-growing, polyploid strains of *Palmaria*, and then select for an optimal morphology and growth rate.

Porphyra

The red alga that has the greatest potential for aquaculture success in our region in the shortest amount of time is *Porphyra*, commonly called "nori" . Nori is a major source of food for humans in the Far East and is becoming increasingly popular in the United States and Canada. *Porphyra*'s main use is in the Japanese delicacy known as "sushi" and is considered to be a valuable health food.[17] Nori is rich in protein (up to 45% of content), vitamins C and E, beta carotene, and EPA.[17,18] It is also an important commercial source of the red pigment r-phycoerythrin, which is utilized as a fluorescent "tag" in immunofluorescent studies.

Porphyra's cultivation is already well established and widely practiced in Japan and China. In 1991, Coastal Plantations International (CPI), initiated efforts to develop *Porphyra* farming in Cobscook Bay, Maine.[1] Currently, CPI is cultivating a non-indigenous species of *Porphyra*, *P. yezoensis* strain U-51, which was developed for superior taste and growth in Japan. CPI received permits from international, state and local agencies to introduce *P. yezoensis* into the waters of Cobscook Bay, Maine, after it provided evidence that temperature and daylength conditions in the area would prevent sexual reproduction from occurring. Although spread from monospores was initially a concern, recent field recruitment studies by Watson et al.[19] suggest that *P. yezoensis* cannot overwinter and establish a year-round population in Cobscook Bay. Thus, although *P. yezoensis* is an introduced species, it appears safe to culture in at least some parts of our region and it has the advantage of having a well-established and substantial market.

In order to help develop a viable *Porphyra* cultivation industry in our region, we have been working for the past three years to develop new strains of *Porphyra yezoensis* specifically for cultivation in northern Maine waters. In particular, we are attempting to produce a strain that will exhibit better summer growth and unaltered reproductive traits. Using a novel new approach to protoplast fusion in *Porphyra*, we have succeeded in fusing protoplasts between *P. yezoensis* and one of the local *Porphyra* species, *P. umbilicalis*. Although our results are still preliminary, evidence to date suggest that we have produced for the first time a polyploid strain of *P. yezoensis*. This plant (#9-13) has a higher than normal DNA content and number of chromosomes,[12] and exhibits a significantly faster growth rate, at least in laboratory culture. Its EPA content and taste traits are being investigated.

Conclusions

In conclusion, seaweed aquaculture in our region is most likely to succeed by developing aquaculture systems for one or more species that produce high-valued specialty products. One way to reduce costs would be to grow more than one species with similar cultivation requirements at the same facility, for example *Chondrus* and *Palmaria*. Another way to reduce costs would be to use seaweeds to remove nutrients produced in fish aquaculture systems either on land or in the ocean.[20] However, regardless of how the seaweed is grown, it must produce a product that is valuable enough to justify its cultivation. Although we are limited today in the types of valuable products seaweeds can produce by their genetic composition, we will soon be able to introduce new genes and therefore completely new traits into seaweeds using genetic engineering techniques. As with agriculture, I believe genetic engineering will provide exciting new opportunities for seaweed aquaculture that will revolutionize the industry.

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Seaweed Aquaculture Potential in Newfoundland — Habitat Quality and Suitable Native Species

R. Hooper

Aquaculture accounts for most of the world's multi-billion dollar seaweed industry. The coast of Newfoundland has advantages and disadvantages as a site for new seaweed aquaculture development. The advantage is that Newfoundland has a vast unpopulated coast with little other activity that would compete, or be impacted by, seaweed farming. Much of the Newfoundland and Labrador coast has nutrient-rich, cold, clear seawater that is ideal for rapid seaweed growth. Unlike finfish farming, low seawater temperatures are a virtue rather than a problem for seaweed culture. Seaweed farms produce no organic or antibiotic wastes and can even be used to reduce nutrient loading from adjacent finfish sites. One disadvantage of Newfoundland as a site for seaweed aquaculture is the extended period of winter ice, although seaweed can be easily grown during the ice-free periods. Developing lucrative markets in competition with third-world countries is also a potential problem. Although Newfoundland cannot hope to produce low-value phycocolloids, local species such as nori (*Porphyra* spp.) and the kelps *Alaria*, *Laminaria*, and *Saccorhiza* are worthy of consideration for aquaculture. This paper reviews the habitat requirements for seaweed aquaculture in the Newfoundland context.

Introduction

There has been little interest in seaweed culture by industry, government, or the public in North America (and Newfoundland). It is not generally appreciated that seaweeds are a very important sector of aquaculture in the world,[1] with an annual value in the billions of dollars and employing hundreds of thousands of workers. Labor-intensive farming of low-value kelp species and carrageenan-producing red algae for marine colloid production accounts for most of the tonnage, while high-value seaweeds for human consumption accounts for much of the dollar value.[2,3]

In spite of the low public awareness, information necessary for the development of an Atlantic Canadian seaweed aquaculture industry does exist. The National Research Council's Institute for Marine Biosciences has been working on seaweed aquaculture in the Maritime Provinces for over 30 years[4] and have provided a wide background of relevant biological, chemical, and technological information.

Seaweed aquaculture has not received significant attention in Newfoundland, although the wild seaweeds and their habitats are quite well known.[5,6] Newfoundland has therefore been missing out on a potentially valuable expansion of the local aquaculture industry. The objective of this report is to review selected aspects of Newfoundland's habitat and local seaweeds.

Marine Physical Habitat

Water temperature

Seawater temperatures in Newfoundland range from the freezing point in the winter to relatively warm conditions in the summer. Inshore summer temperatures are considerably warmer than the frequently cited offshore surface isotherms.[7] In western Newfoundland, summer seawater temperatures may reach 20°C, while temperatures on the south and east coasts seldom exceed 15°C.[6] Labrador and the eastern side of the Northern Peninsula are much cooler in summer than other areas of Newfoundland and seawater temperatures only reach 5 to 10°C. There are also considerable year to year fluctuations in seawater temperature in Newfoundland and Labrador.

Light

Newfoundland is handicapped with respect to irradiance. The amount of light penetrating the clouds and fog is as much as 40% lower than is usual at this latitude.[8] However, the seawater off Newfoundland is exceptionally clear, so the irradiance reaching submerged plants may not be a problem. More data are required.

Wave climate

Exposure to storm waves varies geographically and seasonally.[7] Most of the Newfoundland coast is highly convoluted and there are innumerable sheltered harbors. In western Newfoundland, pack ice in the Gulf of St. Lawrence and limited fetch combine to protect this coast from major winter wave exposure. In the rest of Newfoundland, however, autumn and winter wave exposure is extreme along the open coast.

Substrata

Most of the Newfoundland coast is rocky. Even sheltered harbors are seldom very sedimentary. Most aquaculture sites are therefore more suitable for anchored aquaculture systems rather than structures that are driven into the seabed. Suspended sediments will not be a problem in most locations.

Pollution

Newfoundland is very sparsely populated and industrialized. Pollution is limited to domestic sewage in populated harbors, and industrial waste from three paper mills and assorted fish plants. There is little risk of contamination in most areas. The pristine quality of the marine environment should be a marketing asset. Natural nutrients for plant growth are seasonally variable, with the highest values occurring in the winter. Upwelling is frequent in many areas.

Ice

Most of the Newfoundland coast is subject to pack ice, land-fast ice, or both. Pack ice can devastate anything it contacts when it reaches the shore (Fig.1). In these areas seaweed aquaculture would need to adapt existing techniques to minimize ice damage. The south coast of Newfoundland between western Placentia Bay and Cabot Strait is generally ice-free and represents the most suitable area for year-round aquaculture.

Native Seaweeds for Aquaculture

There may be opposition to the introduction of alien seaweed species into Newfoundland. This opposition may be based on fear of introducing species that may displace local species, potential for damage to existing fisheries, potential for new fouling problems, or even xenophobia. Regulatory agencies will have to approve introductions, so if they are to occur, we should anticipate the need to deal with potential objections. Introduced species have advantages in terms of existing markets and technology, and may well be the best choice for some operations. Introduced species also include cultivated varieties that may be more productive or otherwise superior to wild stock.

Native seaweeds may also have advantages. The regulatory bureaucracy will be much easier to deal with. Native species have demonstrated their suitability to local marine climatic conditions and should therefore be less susceptible to environmental stress. I am sure that slightly exotic species, closely related to traditional species, could readily attract a market niche. A brief discussion of some local species follows.

Figure 1. Pack ice that has grounded on the beach at Sally's Cove, western Newfoundland, March 1992.

Kelps

Wild kelps thrive in the exposed, rocky, cold, full- salinity habitats of the Newfoundland coast. Several local species have excellent culinary properties. All should be easily cultured with variations on standard rope culture techniques.[9] Several species that are particularly favored by local oriental chefs are discussed here:

- *Alaria esculenta*, sometimes referred to as the winged kelp, may be the most common fleshy seaweed of Newfoundland's exposed rocky shores. It grows very quickly in suitable cold, wave-exposed sites. Kelp with the best food quality is produced in the winter and spring. This species is particularly heat sensitive and dies back almost totally if temperatures exceed about 13°C.
- *Saccorhiza dermatodea* is Newfoundland's only annual kelp species. Small blades appear in March and April and develop through the spring and summer. In most of Newfoundland, it is only edible while young and tender in the spring. In Labrador it is edible all summer. Aquaculture would require harvest of spores in the early autumn to establish gametophyte cultures for subsequent use. Wild populations are highly variable in growth rate and size, so selection for the best quality varieties will be advisable.
- *Laminaria longicruris* is Newfoundland's largest kelp (Fig. 2), often exceeding 8 m in total length. Aquaculture would probably be best directed to smaller, tender, tasty, young specimens. Wild populations of this species are most abundant at more sheltered sites than the other kelps mentioned here. It is also more tolerant of higher summer temperatures, so it may be the easiest species to culture.
- Wild *Laminaria digitata* (finger kelp) thrives in very exposed, rocky habitats. Young specimens are very tasty and tender in the spring. Larger plants become too tough to eat, while summer metabolism results in an unpleasant bitter flavor. This species is superior for feeding to sea urchins to enhance their gonad yield and commercial quality.[5]

Nori

Several species of *Porphyra* grow naturally in Newfoundland. The suitability of any of these for aquaculture requires research. The Japanese species of Nori, *P. yezoensis*, is being successfully farmed in Maine, and therefore should be suitable for culture in Newfoundland.[2,3]

Figure 2. *Laminaria longicruris* at 5 m depth, Gadds Point, Bonne Bay, estern Newfoundland, March 1992.

Other seaweeds

The potential for farming other algal species requires further research. Irish moss is being grown in tank culture in Nova Scotia,[4] and this or other species could be cultured in Newfoundland if the economics make sense.

Other Challenges to Seaweed Aquaculture in Newfoundland

Herbivores

Numerous native marine herbivores are capable of eating seaweed crops. Perhaps the most serious is the snail *Lacuna vincta* (Fig. 3). *Lacuna,* and several other small gastropods grow, mature, and reproduce very quickly. This allows initially small populations to rapidly infest young kelp beds. These snails not only devour the crop but also render it unpalatable. If these species become pests, then controls will need to be developed. Other rapidly reproducing herbivores include gammarid amphipods and isopods.

Longer-lived herbivores will also pose a threat to seaweed farms. Many Newfoundland sites are dominated by sea urchins (Fig. 4) and periwinkles. These voracious animals will seize any opportunity to invade tasty seaweed farms. They should be relatively easy to exclude, if proper precautions are developed. Joint management of sea urchins and seaweeds is advisable.

Fouling

Many plants and animals can foul algal crops. These include hydrozoans, bryozoans, mussels, clams, serpulid worms, tube-building amphipods, scores of algae species, and many other organisms. Fouling is minimal when seaweed growth is greatest. Harvest should be timed before fouling becomes severe, if practical.

Disease

All seaweed species are subject to attack by pathogenic fungi, bacteria, viruses, seaweeds, nematodes, or other detrimental organisms. Crops such as Japanese nori that have been farmed for centuries have a relatively well-known suite of diseases. For less traditional seaweed crops, numerous new diseases will be described. Most seaweed diseases are not important to rapidly growing plants in cold water. Older plants, and plants growing at high water temperatures, are particularly susceptible to disease. Disease control will require considerable ingenuity.

Resource conflicts

The traditional fishing community will view any new development in Newfoundland's coastal waters with suspicion. It is vital to consider this at the earliest stages of aquaculture development. All reasonable care must be taken to ensure that aquaculture developments do not impact on existing fisheries. It will be even more important to prevent negative perceptions of aquaculture, as perceptions may well outweigh facts. Communication with other marine stakeholders must be established and maintained.

I am indebted to Memorial University for allowing me to pursue knowledge of Newfoundland's seaweeds and their habitat. Innumerable colleagues, including Drs. A. Whittick, M. Guiry, D. Cheney, C. Yarish, J. Pringle, G. Sharp, W. Farnham, and R. Fletcher have provided valuable insight and discussion.

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Figure 3. The snail, *Lacuna vincta,* eating the surface tissue of the annual kelp, *Saccorhiza dermatodea*, 2 m depth, Point Amour, southern Labrador, August, 1993.

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Marine Agronomy in the Atlantic Provinces: Reality or Fantasy?

Ira A. Levine

Commercial cultivation of the red alga *Porphyra* (nori) was initiated in Cobscook and South Bays, Maine, in 1991 by Coastal Plantations International, Inc. (CPI). The company's efforts with nori have resulted in the world's first internationally certified, organically cultivated and processed nori. Additionally, a pilot project was initiated to establish an integrated nori and salmon polyculture system. CPI's attempt to cultivate nori in the waters straddling the international border was followed by a two-year effort to secure the licenses and permits for a nori farm in New Brunswick. In contrast with its Asian counterparts in the nori industry, the American industry is completely vertically integrated because CPI is the sole participant. The company has had to develop corporate, financial, scientific, regulatory, political, engineering, marketing, distribution, and socio-economic expertise to develop the emerging industry to its current status. CPI has produced nori farming manuals and offered short seminars and a 6-month training course in hopes of recruiting the next generation of independent nori farmers. The company desires to support independent nori farming and polyculture concerns from Newfoundland to Long Island Sound. Entry requirements include site selection, permitting, farm training, equipment acquisition and assembly, primary processing, and the discipline to tend to a farm on a daily basis. CPI encourages and will support new farming efforts in the Atlantic Provinces of Canada. Farming economics, barriers to entry, and a forecast of the future of Canadian nori farming are presented in this report.

Introduction

The red alga *Porphyra* (nori) is utilized by humans as a food source throughout the world. In 1996, approximately 14 billion sheets (approximately 44 000 dry metric tons) of *Porphyra* were produced with a value of US$1.6 billion. Nori has long been prized as a complement to rice, sushi, soups, and salads by the Japanese, Chinese, Koreans, and other Asians. Additionally, nori is a staple in macrobiotic diets, a source of taurine, which controls blood cholesterol levels, and a valuable source of phycoerythrin, a red pigment used in the medical diagnostic industry. Before Coastal Plantations International (CPI) entered the market, the consumption of nori in the United States was dependent upon imports from Japan, Korea, and China. Americans consume nori primarily in Japanese restaurants rather than preparing sushi at home or using it in other traditional ways. CPI is trying to expand the uses of nori in America through the development of alternative foods and industrial uses.

Commercial cultivation of the red alga *Porphyra yezoensis* (nori) was initiated in 1991 in Cobscook and South Bays, Maine, following efforts by other companies in Washington State in the 1980s. The transfer and modification of cultivation and processing technology from Japan, Korea, China, and Washington State resulted in the development of the world's first internationally certified, organically cultivated and processed nori. In addition, we have established an integrated nori and salmon polyculture system .

CPI's progress has resulted in the formation of two divisions within the company. The Maine Nori Company represents CPI's effort to produce and market organic nori and develop new products and marketing strategies for commercial seaweeds in North America and beyond. PhycoGen is a marine biotechnology research and product development effort, whose goals are to produce new industrial products and drugs through the development of transgenics, natural product discovery, site directed mutagenesis, phycoremediation, and genetic transformations via protoplast fusions. The following applications are representative selections of pending and future applications of PhycoGen's efforts: natural sunscreen, nori pigments, cosmetic ingredients, phycoremediation, antifouling paints and edible vaccines.

CPI imported the Japanese cultivar *Porphyra yezoensis* to the waters of Cobscook Bay due to the unsuitability of the indigenous species to commercial culture. The introduced *P. yezoensis* could be improved by incorporating certain characteristics of Maine's local varieties. To that end, a cultivar improvement program was initiated utilizing proprietary protoplast fusion and mutagenesis techniques to be followed by strain selection.

PhycoGen and its satellite laboratory system, along with a consortium of university phycologists in New England, have domesticated the local species, developed new fusion products, and used biotechnology to produce higher value products. This private/public partnership has significantly improved the potential for a permanent marine agronomic industry in the coastal waters off New England and the Canadian Atlantic Provinces.

CPI set out to develop new and faster growing strains of *Porphyra* for farming in the western North Atlantic and Pacific Oceans. The success of nori cultivation is a function of matching a cultivar to special environmental conditions. The original cultivar, *Porphyra yezoensis*, was imported from Japan and is not an ideal species for northern Maine waters. Therefore, hybrids have been developed utilizing genetic modification, manipulation, and transformation techniques. The use of CPI's proprietary and licensed technologies has resulted in the development of "Super Nori".

Canadian Nori Farming History and Perspective

Following the introduction of nori farming to Washington State in the mid 1980s, approvals were granted for the introduction of *Porphyra yezoensis* and frozen nori nets to Victoria, British Columbia, in the late 1980s. Nori was farmed for approximately 3 years before the effort collapsed due to factors that included damage to the cultivation systems from winter storms, insufficient site selection efforts, lack of biological and farming experience, and an under-capitalized financial base.

In 1991, an application was submitted by CPI to the Province of New Brunswick's Department of Fisheries and Aquaculture to introduce *Porphyra yezoensis* and nori farming to Harbor DeLute, Campobello, adjacent to an existing salmon farming operation. Extensive review by biologists at the provincial Departments of Environment and Fisheries & Aquaculture and the federal Department of Fisheries and Oceans led to approvals after 28 months. The introduction and assembly of a small pilot test farm was initiated in the spring of 1994. Difficulties encountered by CPI included accessibility, the requirement for cross-border work permits, and the logistics of customs declaratios, which restricted the company's efforts and ultimately resulted in the closure of the pilot project. Growth rates realized in the short effort indicated a real potential for a commercial nori farming operation.

As a result of the difficulties encountered in New Brunswick, CPI is reluctant to be the active farming participant in nori farming efforts in the Atlantic Provinces. It has however supported subsequent efforts by Canadian companies. CPI relies on potential Canadian nori farmers to complete the aquaculture lease site permitting process. CPI will support efforts by supplying site selection criteria, training in nori farming, equipment and supply needs, and eventually seeded nori nets.

CPI has received a number of nori farming inquiries from New Brunswick, Nova Scotia, Newfoundland, and Prince Edward Island. As a result, one test farm introduced a small number of seeded nori nets to Grand Manan in 1997. The less than favorable results were due, in part, to insufficient capital to initiate the farming effort, lack of complete cooperation from provincial officials, and inadequate site selection and training.

Canadian Nori Farming — Future Potential

Presently, CPI is permitted to introduce the Japanese cultivar into the waters of the Gulf of Maine which include the waters of New Brunswick and the western coast of Nova Scotia. The eastern shore of Nova Scotia and Newfoundland lie outside of this water body. Therefore, at the present time only local species of *Porphyra* can be utilized in a farming effort. Each year the company reports to the United Nations' International Council of the Exploration of the Seas (ICES), which could review an application to introduce the commercial cultivar to these excluded areas. An applicant or farmer would have to petition the province, who in turn petitions the federal government, which would make a formal request to the ICES Secretary General, who would refer the request it back to the ICES working group on international introductions and transfers. The key to an abbreviated review would be the determination of similar environmental conditions as experienced in the Gulf of Maine (temperature and day length).

Farming permits are a function of provincial review and control. New Brunswick has exhibited inconsistent attitudes concerning the introduction of an exotic species as well as the issuance of nori farming permits. The future potential of nori farming in the Atlantic Provinces is in the development of a nori:finfish farming partnership. The development of nori:finfish integrated polyculture systems has many advantages, including established aquaculture infrastructure, sufficient capital base, and the inherent advantages in polyculture.

CPI established a nori:finfish polyculture test farm in 1996. The effort realized significantly elevated growth rates and superior pigment content as compared to CPI's independent production facilities. The availability of excess nitrogen and phosphorus, the stability of anchoring systems, and the utilization of staff experienced in aquaculture resulted in an unqualified success. The salmon companies could realize both the value of a second cash crop and the significant reduction of nitrogen and phosphorous exported to the environment from salmon waste production.

Conclusions

The potential is high for a successful nori farming industry in the Canadian Atlantic Provinces. With the decline in the commercial fishing industry and the pressures that the finfish industry may face from regulators and environmental groups concerning effects of farming on the environment, nori farming represents an attractive alternative. The labor force of experienced aquaculture and marine-based workers, the availability of pristine waters, and a source of high quality nori-seeded nets offers a bright future for this new industry. If the provincial and federal governments support these efforts within the permitting process, the potential for success would be significantly increased.

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Seaweeds Must Be a Significant Component of Aquaculture for an Integrated Ecosystem Approach

T. Chopin and C. Yarish

After rapid expansion throughout the world, and particularly in areas like the Bay of Fundy, the aquaculture industry is beginning to realize that its present monospecific approach has economic and environmental limitations. The development of integrated aquaculture practices is necessary and timely in light of the recent crises experienced by the salmon industry. Using a balanced ecosystem approach, polyculture operations should include seaweeds used as biological nutrient removal systems. Seaweeds not only participate in the bioremediation of nutrient-enriched coastal waters, but are also a high-value crop that diversifies sources of revenue and the labor force of the aquaculture industry. Two species of the red alga *Porphyra, P. yezoensis* (nori for direct human consumption) and *P. purpurea* (for biotechnology markets), are able to detect high nutrient loading resulting from anthropogenic activities such as salmonid aquaculture and intense scallop dragging which resuspends nutrients trapped in sediments. These seaweeds are extremely efficient nutrient pumps and should be excellent candidates for integrated aquaculture and bioremediation, as their frequent harvesting amounts to constant removal of significant quantities of nutrients from coastal waters. The development of integrated aquaculture systems, however, will only come about if there is a major change in social, economic, political, and funding thinking so that sustainability, long-term profitability, and responsible management of the coastal zone are sought.

Introduction

All too often in opening plenary presentations at aquaculture conferences, the seaweed aquaculture sector is omitted when the latest global picture of the world aquaculture industry is given. The reduced concept of aquaculture predominating in Atlantic Canada, where aquaculture means finfish and shellfish culture (and even more narrowly, salmon and blue mussel culture), is not shared in other parts of the world where people think of seaweed aquaculture long before finfish or shellfish aquaculture. The value of the red alga *Porphyra*, commonly known as nori, cultured for direct human consumption (especially as sushi) is estimated at US$2.0 billion in Japan alone,[1] equivalent to the entire global value of the blue mussel industry. The aquaculture of approximately 10 algal genera in China has gone through unprecedented development over the last decade and now reaches an annual value of US$300 million.[2] The development, since the early 1970s, of farms of the red alga *Eucheuma* in the Philippines has established that country as the dominant supplier of raw material for the carrageenan industry. Carrageenans are worth US$280 million annually, while the total phycocolloid industry is estimated at US$623 million.[3]

After rapid expansion, the salmon aquaculture industry has experienced several crises in recent years. As a consequence, there has been some evolution in the industrial, political and public opinion of the industry and increasing interest in "new" or "alternative" species for aquaculture (even if the species are not "new", the type of aquaculture could be). However, it is once again obvious that most people display a "zoological bias" or "kingdom-neutral incorrectness", deeply rooted in our educational system. Alternative species, to most Atlantic Canadians, means other species of finfish. But replacing one fish with another does not significantly alter the processes taking place in coastal waters with intensive aquaculture operations. Whatever its binomial identification or vernacular name, a fish consumes oxygen and excretes large amounts of nutrients and organic matter. Introducing another species of fish may add up economically, but it does not balance biologically. Few people are ready to make the next logical step towards sustainable aquaculture practices. Seaweeds undertake most of these physiological processes "in reverse": they photosynthesize and hence produce oxygen (at least during the day) and take up nutrients. Consequently, they should be integrated with other species so as to develop a balanced ecosystem approach to responsible aquaculture. It is also important to note that while seaweeds address the issue of inorganics produced by fish farms (nutrients, mostly nitrogen (N) and phosphorus (P)), they do not address that of organic matter, which should be taken care of by suspension-feeding organisms as another component of an integrated culture system.

The aquaculture industry is starting to realize that its present monospecific approach has economic and environmental limitations. Economically speaking, overproduction has led to a significant price decrease in recent years. International competition is greater, and, as already realized on land, monoculture dangerously limits economic diversification, and an overspecialized labor force reduces alternative employment opportunities. Environmentally speaking, Enell and Ackefors[4] estimated that 9.5 kg of P and 78 kg of N per tonne of fish per year are released into the water column. With global salmon production of 644 092 tonnes in 1996, this represents the P and N equivalent of untreated sewage from 10 million people. It is obvious that each habitat can only carry a certain level of monoculture before a disequilibrium develops, and that if aquaculture exceeds the carrying capacity of coastal waters, it can generate severe disturbances, including diseases, eutrophication, toxic blooms and green tides.[5]

Different methods have been used to try to minimize the effect of nutrient loading; however there are still significant amounts of P and N not consumed or released as feces.[6] One solution is to develop integrated polyculture systems in which "wastes" are valued (as fertilizers) and managed (the wastes of one resource user become a resource for others). Kautsky et al.[7] developed the concept of "ecological footprint", which is the life support area needed per square meter of aquaculture activity. For 1 m^2 of salmon aquaculture, the N production requires 340 m^2 of pelagic production to be assimilated, and the P production requires 400 m^2 of pelagic production. By integrating the culture of the red alga *Gracilaria* to salmon aquaculture in Chile, these authors were able to reduce these ecological footprints to 150 m^2 for N and 25 m^2 for P.

Development of Nori and Integrated Aquaculture in New England and Atlantic Canada

We are developing, with colleagues at several universities in New England and the company PhycoGen, Inc. from Portland, Maine, a program of integrated aquaculture by replacing *Gracilaria* (for the agar market) with *Porphyra* (for direct human consumption and biotechnology markets).

A previous study[8] demonstrated that *P. yezoensis* and *P. purpurea* are able to detect high nutrient loading in coastal waters resulting from anthropogenic activities (salmon aquaculture and intense scallop dragging, which puts nutrients trapped in sediments back into suspension), and, consequently should be excellent candidates for integrated aquaculture and bioremediation. In December 1996, *P. yezoensis* on nets close to salmon cages at Deep Cove in Cobscook Bay, Maine, reached high levels of P and N (7.9 ± 0.4 mg P/g DW and 66.4 ± 1.4 mg N/g DW) which corresponded to high levels of P and N in the seawater (0.93 µM P and 11.23 µM N). *Porphyra purpurea* at Dipper Harbour, New Brunswick, a location remote from the two above anthropogenic activities, showed lower levels (3.2 ± 0.1 mg P/g DW and 46.3 ± 0.0 mg N/g DW), corresponding to lower levels in seawater (0.68 µM P and 6.87 µM N). In November 1997, *P. purpurea* growing on the buoys of the anchoring system of salmon cages at Deep Cove reached high levels (7.1 ± 0.8 mg P/g DW and 62.5 ± 0.4 mg N/g DW), corresponding to high levels in seawater (0.91 µM P and 10.59 µM N). In contrast, *P. purpurea* growing on rocks on the shore at Huckins (in Cobscook Bay, but far from aquaculture sites) had lower values of 3.3 ± 0.5 mg P/g DW and 44.8 ± 0.6 mg N/g DW. It should be pointed out that the levels of P and N reached by *P. yezoensis* and *P. purpurea* are very high. For comparison, the red alga *Chondrus crispus* has tissues saturating at around 4.5 mg P/g DW.[9] The highest nitrogen contents recorded by Chopin et al.[9,10] are 45.1 and 43.0 mg N/g DW in the red algae *C. crispus* and *Polysiphonia lanosa*, and 41.4 and 26.8 mg N/g DW in the brown algae *Pilayella littoralis* and *Ascophyllum nodosum*.

From the above data, *Porphyra* can be considered an extremely efficient nutrient pump, undoubtedly associated with its morphology (thin blade with 1 or 2 layers of cells, all involved in absorption). It could be argued that this morphology, while creating an efficient pump, does not allow storage in reserve tissues like those in the large brown algae (Laminariales, Fucales). However, the advantage of *Porphyra* is its rapid growth, which allows the harvest of a crop every 9 to 15 days.[11] Frequent harvesting amounts to constant removal of significant quantities of nutrients from coastal waters, which validates the concept of using *Porphyra* as a biological nutrient removal system integrated with finfish aquaculture.

Based on the estimates of Enell and Ackefors,[4] the contents reached by *P. purpurea*,[8] and the nori production that can be obtained from nets,[11] we calculated the number of nori nets necessary for the bioremediation of the nutrification process per tonne of fish per year.[12] To remove 9.5 kg of P and 78 kg of N per tonne of fish per year, 37 and 35 nets would be necessary, respectively. It is interesting to note that approximately the same number of nets would take care of both P and N nutrification. Moreover, 37 nets over a year are a very reasonable number of nets to manage. Several points, however, need to be made: 1) these calculations need to be refined by integrating the possibility of variations in absorption of nutrients by plants at different seasons, and between the different species of *Porphyra*; 2) these calculations are for the complete "scrubbing" of P and N resulting from aquaculture operations; and 3) it may not, however, be the ultimate target, which should be the development of enough nutrient competition by cultivation of desirable algal crops to reduce nutrient concentrations in seawater and the biomass of problem species below the threshold of devastating and costly hypertrophic events, such as eutrophication, diseases, harmful algal blooms, and green tides,[13] in which case, a lower number of nori nets would be necessary.

Conclusions

1. Seaweeds of commercial value, and particularly *Porphyra*, can be used in the bioremediation of coastal waters by the development of a balanced polyculture ecosystem approach, instead of the present unsustainable monospecific industry.
2. *Porphyra* cultivation could allow economic and labor diversification from the monoculture salmon industry, already near saturation.
3. Nutrients produced by salmon aquaculture could fertilize the seaweeds at no cost, especially during nutrient-limited periods (i.e., summer). Consequently, higher nori production could be anticipated in an integrated system compared to an exclusively nori farm.
4. If *Porphyra* reveals itself as an efficient biological nutrient removal system, the possibility of increasing the number of salmon cages at a particular site could be contemplated.
5. The introduction of a competition for nutrients by cultivation of desirable algal crops should reduce the biomass of problem species below the threshold of devastating and costly hypertrophic events.
6. The decision to develop integrated aquaculture systems, however, will only occur if there is a major change in social, economic, political, and funding reasoning so that sustainability, long-term profitability, and responsible management of the coastal zone become goals. But to develop successful integrated aquaculture, there needs to be:
   a) A clear commitment from the various players (suppliers of nets, farmers, processors of nori sheets or other applications, scientists, funding agencies and different levels of government), as well as a clear respect and appreciation of their respective contributions, while recognizing their specificities.
   b) A clear understanding of the necessary role and mission of research and development. The order of these words (or their initials) is of profound significance: it is R&D, not D&R! One should not forget, for example, that the present development of nori aquaculture in Asia is due to the scientific discovery of the life cycle of *Porphyra* by Kathleen Drew in 1949,[14] not the reverse.
   c) A recognition that R&D and monitoring are important components of any economic development/business plan and have a cost, which should be factored in from the start and not at a later stage after having been forced (but not necessarily convinced of its indispensable implementation) by some regulations.
   d) Finally, not to forget that some agricultural practices have taken centuries to fully develop and that aquaculture is still in its infancy.

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Calendar

• AQUATECH '99, 27 – 30 July 1999, University of New Brunswick. AQUATECH '99 will be integrated with BioAtlantech 1999 and focus on the development of genomics and nutraceuticals for agriculture, aquaculture and forestry. Registration information, telephone 506 444-2444, fax 506 444 5662, e-mail jgartley @fundy.net. Website: http://www.bioatlantech.nb.ca.

• **Aquaculture Europe '99**, 7 – 10 August 1999, Trondheim, Norway. Being held immediately prior to the AQUA NOR 99 trade show.Topics: egg quality; larviculture, with focus on quality of offspring; fish health including viral diseases of fish and vaccination programs; genetics; interactions of farms with the environment; marketing of aquaculture products; and harvesting and market quality. Information: EAS Secretariat (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@unicall.be, website http://www.Easonline.org).

• **5th Simposio Centroamericano de Aquacultura,** 17 – 20 August 1999, Hotel Mare Mares, San Pedro Sula, Honduras. Sponsored by the Latin American Chapter of the World Aquaculture Society. Information: John Cooksey, Aquaculture Venezuela V Symposium, 21710 7th Place West, Bothell, Washington, USA (fax 425 483-6319, e-mail worldaqua@aol.com).

• **US Trout Farmers Association Meeting and Trade Show,** 18 – 20 August 1999, Sheraton Inner Harbor Hotel, Baltimore. Program will highlight environmental concerns, such as effluents, and a workshop/short course will be held on fish production. Information: Pat Bethany (tel 304 728-2189, fax 304 728-2196, e-mail ustfa@intrepid.net).

• **American Fisheries Society Annual Meeting, Trade Show and Exhibition,** 29 August – 1 September 1999, Charlotte, North Carolina. Information: AFS 1999 Annual Meeting, Amy Fink. 5410 Grosvenor Lane, Suite 110, Bethesda, Maryland 20814 (tel 301 897-8616 (ext. 214), fax 301 897-8096).

• **ICES Symposium on the Environmental Effects of Mariculture,** 13 – 16 September 1999, St. Andrews, NB. Forum to share research results and enhance international cooperation and collaborative research on 1) the environmental effects of bivalve and fish farming in the coastal zone, and 2) the influence of local environmental factors on mariculture productivity. Information: Dr. D. Wildish, DFO, St. Andrews, NB EOG 2X0 (tel 506 529-5894, fax 506 529-5862, e-mail wildishd@mar.dfo-mpo.gc.ca).

• **Aliia HELEXPO**, 7th International Exhibition of Fisheries, Aquaculture and Relevant Equipment, 23 – 26 September 1999, Thessalonki, Greece. Information: HELEXPO, 154 Egnatia Str., 546 36 Thessaloniki, Greece (tel +30 31 291 111, fax +30 31 229 116).

• **Salmon Summit '99,** 29 – 30 September 1999, Copenhagen. Denmark is one of the world's largest processors of farmed salmon, distributing salmon and salmon products all over the world. The Summit will provide a signifcant opportunity for networking. Lectures will provide insights into new opportunities in the merging markets, distribution, trends in consumer preferecnes and product opportunities. A special feature on Central and Eastern Europe will focus on market possibilities in this emerging market. Information: EASTFISH SALMON SUMMIT, PO Box 0896, D-2100 Copenhagen K (tel +45 35 46 7180, fax + 45 35 46 7181, e-mail fao@eastfish.org).

• **Aquaculture Canada '99**, 26 – 29 October 1999, Victoria Convention Center, Victoria, BC. 16th annual meeting of the Aquaculture Association of Canada and the Pacific Aquaculture Exchange Trade Show. Conference information: Linda Townsend, Fisheries and Aquaculture, Malaspina University–College, 900 Fifth Street, Nanaimo, BC V9R 5S5 (tel 250 741-8708, fax 250 755-8749, e-mail faep@mala.bc.ca, website www.mi.mun.ca/mi/aac/ac99.htm. Trade show information: Master Promotions Ltd. (Tel 506 658-0018, fax 506 658-0750, e-mail show@nbnet.nb.ca). Abstract deadline for contributed papers is 31 August 1999.

• **52nd Annual Meeting of the Gulf and Caribbean Fisheries Institute,** 1 – 5 November 1999, Key West, Florida. Topics include: recent advances in Caribbean aquaculture, management of marine parks and reserves, impacts of anthropogenic activities on marine and freshwater fisheries, marine habitat assessment, recreational fisheries, and the socioeconomics of fisheries management. Information: LeRoy Creswell, Harbor Branch Oceanographic Institution, Inc., 5600 US 1 North, Fort Pierce, FL 34946 (e-mail creswell@hboi.edu).

• **FISH RIGHTS 99 Conference, Use of Property Rights in Fisheries Management,** 11 – 19 November 1999, Freemantle, Western Australia. Conference will explore the strategic, political, and operational issues of different forms of rights-based fisheries management worldwide. Information: Secretariat Office, Petrie International, PO Box 568, Kalamunda, WA 6076, Australia (tel (61) 08 9257 2088, fax (61) 08 9257 2099, e-mail petrcon@iinet.net.au).

• **Marketing & Shipping Live Aquatic Products '99, 2nd International Conference & Exhibition,** 14 – 17 November 1999. DoubleTree Hotel, SeaTac Airport, Seattle. Focus on ornamentals, baits, finfish, shellfish, plants and aquatic foods. Agenda: improved handling technologies, resource management, regulatory concerns, unwanted introductions of non-indigenous species, economics, and animal welfare issues. Information: JB Peters, 5815 NE Baker Hill Road, Bainbridge Island, WA 98110 USA (fax 360 394-3760, e-mail JohnBPeters@compuserve.com, website http://www.alaska.net).

• **Aquaculture Venezuela '99 and 2nd South American Aquaculture Congress,** 17 – 20 November 1999, Puerto La Cruz, Venezuela. Sponsored by the Latin American Chapter of the World Aquaculture Society. Contact: J. Cooksey, Conference Manager, 21710 7th Place West, Bothell, Washington, USA (fax 425 483-6319, e-mail worldaqua@aol.com).

• **Aquaculture America 2000**, 2 – 5 February 2000, New Orleans Marriott, New Orleans, Louisiana. Annual meetings of the US Chapter of the World Aquaculture Society, the American Tilapia Association, Striped Bass Growers Association, AFS Fish Culture Section, and the Lousiana Aquaculture Association. Sessions: freshwater crustacean, tilapia, red drum, marine shrimp, tropical fish, reptile, amphibian, salmonid, molluscan, and striped bass culture; water quality; aquaculture regulations; ploidy manipulaiton and sex reversal; recirculating systems; computers and aquaculture; nutritional requirements and diet formulation for shrimp and fish; and aquaculture as a teaching tool. Information: John Cooksey, Conference Manager, 21710 7th Place West, Bothell, Washington, USA (telephone 425 485-6682, fax 425 483-6319, e-mail worldaqua@aol.com). Deadline for abstracts: 31 July 1999.

• **International Conference on Risk Analysis in Aquatic Animal Health,** 8–10 February 2000, Paris, France. Sessions: the need for risk analysis; risk analysis methodology; areas of application to aquatic animal health including problems, research needs and environmental concerns, case histories and field studies; and recommendations and future prospects. Information: Dr. K. Sugiura, Office International des Epizooties, 12 Rue de Prony, 75107, Paris, France (tel 33 (0)1 44 15 18 88, fax 33 (0)1 42 76 09 87, website http://www.oie.int). Deadline for submission of abstracts: 31 August 1999 — send by e-mail to k.sugiura@oie.int).

• **Conference on Aquaculture in the Third Millennium and Aquaculture and Seafood Fair 2000,** 21 – 25 February 2000, Bangkok, Thailand. Sessions: integrating aquaculture into rural and coastal development; aquaculture and poverty alleviation; involving stakeholders in policy making, planning and management; promoting sustainable aquaculture with economic incentives; building the information base for policy making; establishing legal, institutional and regulatory frameworks; aquaculture production systems; genetics, health management and disease control; nutrition and feeding; culture-based fisheries and enhancement; systems approach to aquaculture management. Exhibitions will be held on aquaculture nutrition and health, seafood and cold storage, and ornamental fish. Exhibition information: Ms Natprapa Yokputtaraksa, Production Management & Services Co., Ltd. (tel 66-2 862-113-4, fax 66-2 862-1132, e-mail pmsco@asiaaccess.net.th).

• **AQUA 2000,** 2 – 6 May 2000, Acropolis Convention Centre, Nice, France. Annual meetings of the World Aquaculture Society and the European Aquaculture Society. A special thematic session running the full length of the conference will focus on responsible aquaculture — can it accomplished? Information: John Cooksey, Conference Manager, 21710 7th Place West, Bothell, Washington, USA (tel 425 485-6682, fax 425 483-6319, e-mail worldaqua@ aol.com). **Abstract deadline 1 October 1999.** For program information check the WAS and EAS websites: http://www.was.org and http://www.easonline.org.

• **Annual Meeting of the Canadian Society of Zoologists,** 3 – 6 May 2000, Algonquin Hotel, St. Andrews, NB. Information: Dr. M. Burt, Huntsman Marine Science Centre, St. Andrews, NB (tel 506 529-1222, fax 506 529-1212, e-mail mburt@nbnet.nb.ca).

• **The 9th International Symposium on Nutrition and Feeding in Fish**, 21 – 25 May 2000, Miyazaki, Japan. Topics include: Challenges and strategies for aquafeed development in the 2000s, nutrient requirements and availability, nutrient metabolism and its control, alternative protein sources, fish health with reference to fish feed, larval and broodstock nutrition, and nutritional strategies and management of aquaculture waste. Information: Prof. T. Takeuchi, Tokyo University of Fisheries, Konan 4, Minato, Tokyo 108-8477 (tel +81-3-5463-0545, fax +81-3-5463-0553, e-mail take@tokyo-u-fish.ac.jp, website http://www.tokyo-u-fish.ac.jp/fish-nutrition).

• **Aquaculture Canada 2000,** 28 – 31 May 2000, Hotel Beausejour, Moncton, NB. 17th annual meeting of the Aquaculture Association of Canada. This millenial conference and exposition will cover a broad spectrum of aquaculture topics and will attract growers, scientists, administrators, educators and students. Information: Dr. Andrew Boghen, Dept. Biologie, Université de Moncton, Moncton, NB E1A 3E9 (tel 506 858-4321, fax 506 858-4541, e-mail boghena@umoncton.ca).

• **Fishery 2000 Guangzhou,** The International Fishery Exhibition, 30 May – 1 June 2000, Chinese Export Commodities Fairground, Guangzhou, P.R. China. Exhibition of seafood, commercial fishing, fish farming and fish processing equipment and technology, seafood transportation systems, refrigeration equipment and technology, and seafood packaging. Information: Top Repute Co., Ltd., Room 2403, Fu Fai Commercial Centre, 27 Hillier Street, Sheung Wan, Hong Kong (tel 852 2851 8603, fax 852 2851 8637, e-mail topreput@hkabc. net).

• **3rd International Conference on Shellfish Safety,** 19– 24 June 2000, Southhampton College, Long Island University, NY. As with previous symposia in this series, presentations will be given dealing with shellfish biology and ecology, chemical and microbiological contamination and assessment, impacts of harmful and toxic algae, depuration technology, monitoring and management, aquaculture and harvesting sites, health and sanitation, and quality assurance programs and regulatory controls. Information: Dr. Sandra Shumway, Natural Science Division, Southampton College, 239 Montauk Highway, Southampton, NY 11968 USA (fax 516 287-8419, e-mail sshumway@southampton.liunet.edu).

• **Coastal Zone Canada 2000**, 17 – 22 September 2000, Reade and Convention Centre, Saint John, NB. Theme: Coastal Stewardship: Lessons Learned and the Paths Ahead. The conference will focus on 4 related subthemes: Aboriginal Practices, Community-based Actions, Coastal Health and Oceans Governance. Information: Coastal Zone Canada 2000 Secretariat, Department of Fisheries and Aquaculture, P.O. Box 6000, Fredericton, NB E3B 5H1 (tel 506 453-2253, fax 506 453-5210, e-mail czczcc2000@gov.nb.ca, website http://www.gov.nb.ca/dfa/czczcc2000.htm.

• **Third World Fisheries Congress,** 31 October - 3 November 2000, Beijing, P.R. China. Topics: Effect of sustainable fisheries on optmizing food composition and improving human health, scientific management, reasonable exploitation and protection of fisheries resources, fisheries technologies, effect of the fishery environment on sustainable development, healthy aquaculture and ecosystems, bio-technology and fisheries, aquatic products processing and comprehensive utilization, bio-diveristy and protection, fishery machinery and instruments, fishery economics, fishery policies and sustainable fisheries development, and application of information technology in fisheries. Conference Secretariat: China Society of Fisheries, Bldg 22, Maizidian Street, Chadyang District 100026, Beijing, P.R. China (tel 86 10 64194233, fax 86 10 64194231, e-mail csfish@agri.gov.cn).