Domestication of nori for Northeast America: the Asian experience

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

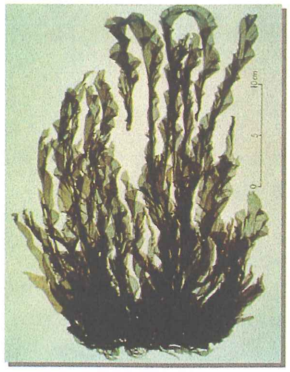
The red alga *Porphyra*, or nori as it is commonly called, is a major source of food for humans throughout the world and is the most valuable cultured seaweed in the world today. In 1992, approximately 15 billion sheets were produced,[1,2] with an annual value of over US$1.8 billion.[3] *Porphyra* is 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

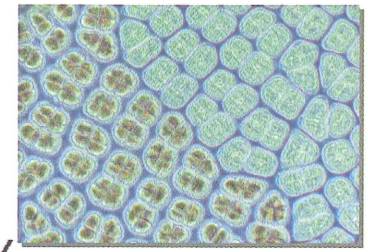
The farming of *Porphyra* was revolutionized in 1949 when Kathleen Drew discovered the diploid shell-boring conchocelis phase of *Porphyra* (Fig. 1). This helped to provide the Asian nori industry with a reliable source of seedstock. Conchocelis is now cul-

Porphyra life history

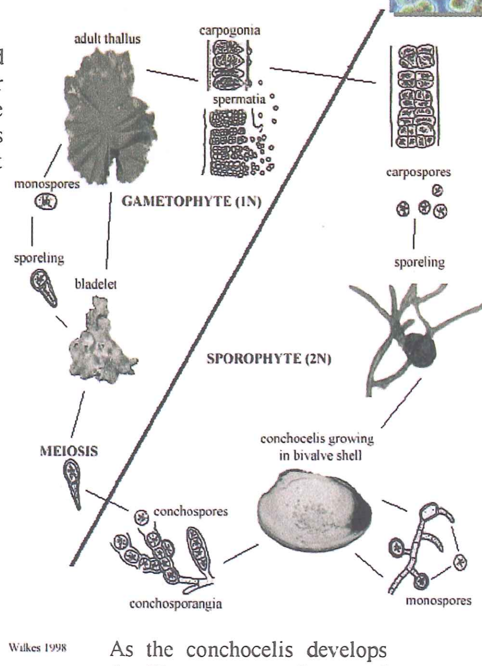
Porphyra yezoensis is the most commonly used species in commercial farming. The haploid blades germinate from conchospores released by the conchocelis-phase of the life history.



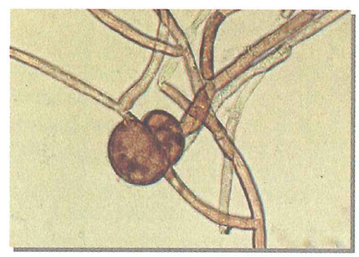
As the blades matures spermatangial and carpogonial tissue forms in patches towards the edges of the thallus



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

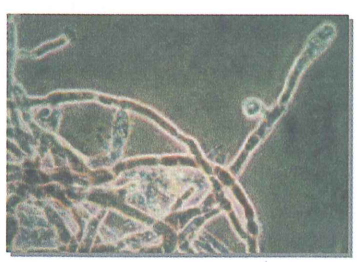


Figure 1. Life history of *Porphyra*. Note how the haploid blade generation alternates with the diploid filamentous shell-boring conchocelis generation.

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

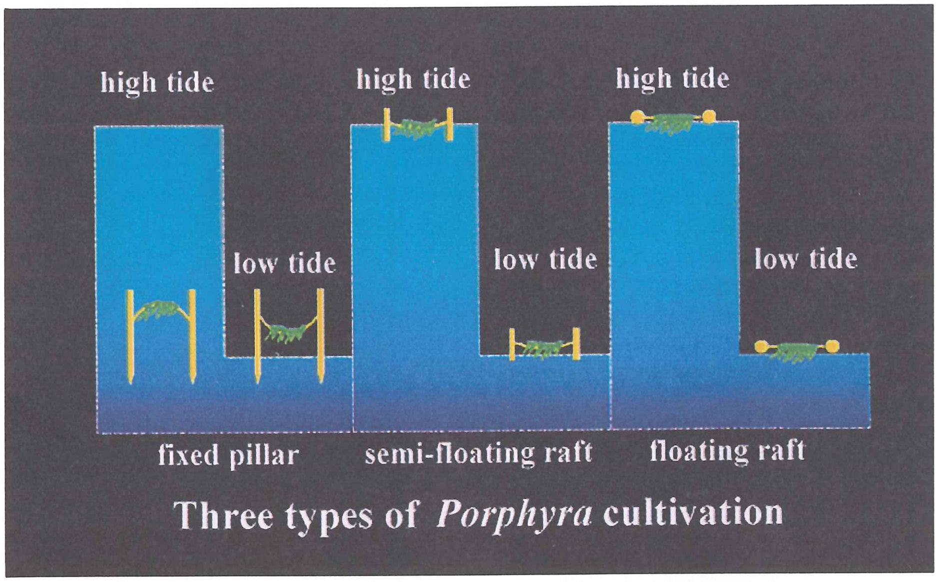


Figure 2. Three basic types of *Porphyra* culture systems: fixed pole, semi-floating raft and floating raft (after IOEP[23]).

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,

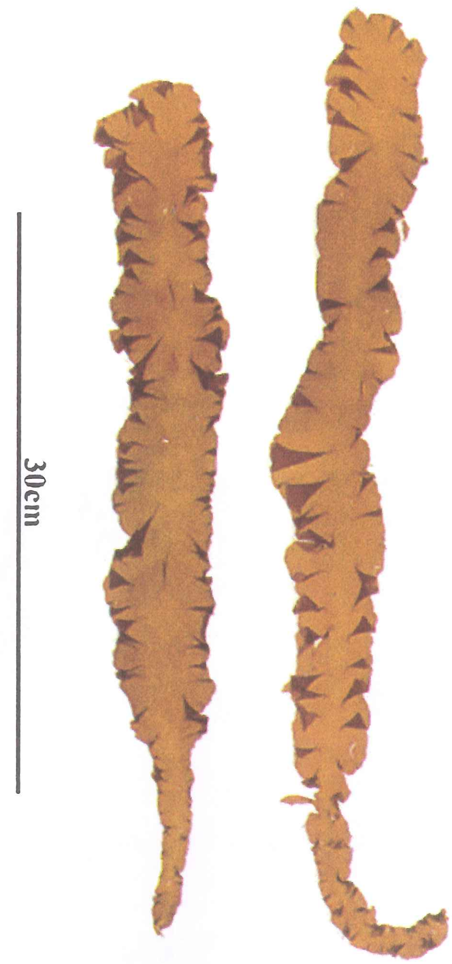


Figure 3. Mature five-week-old *P. amplissima* gametophytes grown in laboratory culture at 100 µmol photon m^{-2} s^{-1} and 10°C under short day conditions. Thallus was grown from a conchospore.

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.

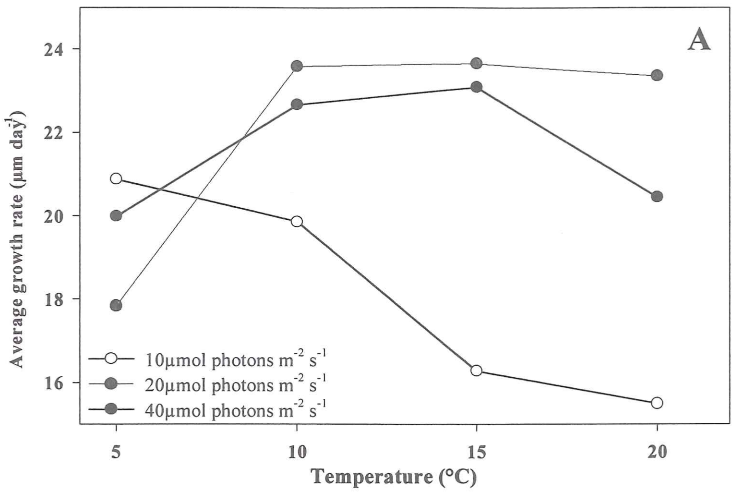


Figure 4a. Mean growth rates of *P. leucosticta* conchocelis grown at four different temperatures and three light intensities at day-neutral

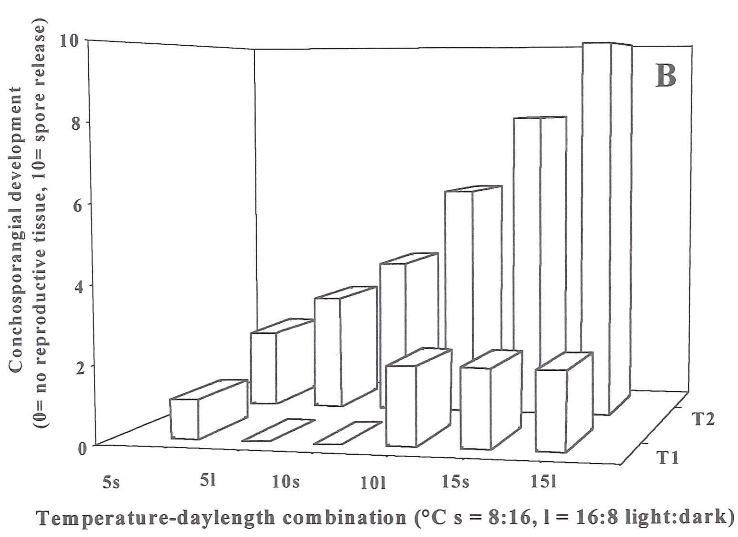


Figure 4b. Conchosporangial development of *P. leucosticta* conchocelis grown at different temperatures and daylengths.

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.

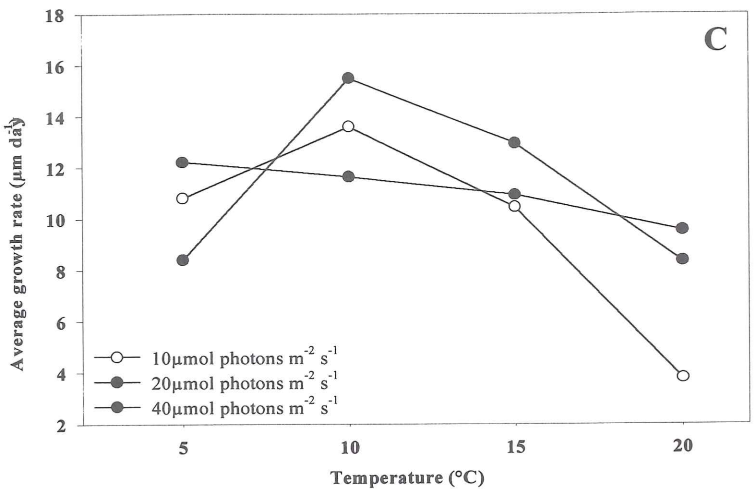


Figure 4c. Mean growth rates of *P. purpurea* conchocelis grown at four different temperatures and three light intensities at day- neutral conditions.

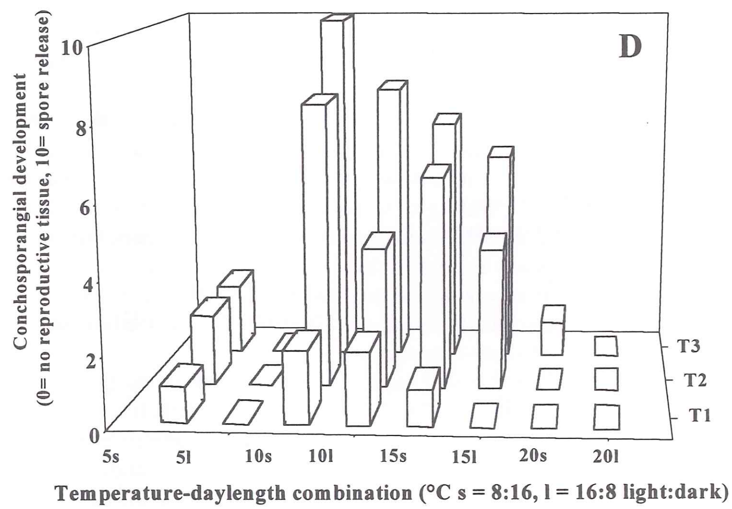


Figure 4d. Conchosporangial development of *P. purpurea* conchocelis grown at different temperatures and daylengths.

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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