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Exploring Northeast American and Asian species of *Porphyra* for use in an integrated finfish–algal aquaculture system

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Abstract

Many aquaculture industries generate a nutrient-rich waste stream that can lead to eutrophication of coastal waters. To address this environmental issue, the bioremediation potential of several native Northeast American species of *Porphyra* was assessed and compared to the well-known Asian species. *Porphyra* thalli were cultured over 4 weeks at 15 °C at a stocking density of 0.4 g FW L^{-1}. At 3- to 4-day intervals nutrient uptake, tissue N accumulation and phycobiliprotein concentration (PBP) were determined as functions of nitrogen (N) concentration (25–300 μM) and N source (nitrate vs. ammonium). Growth rates were measured weekly. Growth and tissue N reached maximal levels at inorganic N concentrations of 150–300 μM. Maximum growth rates ranged from 10% to 25% day^{-1}, although induction of archeospores reduced average growth rates in many cases. No evidence of ammonium toxicity (reductions in growth rate) was observed; in fact, similar values were found with both N sources. Ammonium generally yielded higher PBP and tissue N contents than nitrate. *Porphyra amplissima* presented the highest growth rate, followed by the Asian *Porphyra yezoensis*. Under the experimental conditions, *Porphyra* spp. removed 70–100% of N within 3–4 days at N concentrations up to 150 μM, but was less efficient in removing inorganic phosphorus (35–91% removal). The highest tissue N and PBP concentrations were found at 150–300 μM of N, with N values close to 7% DW. Overall, *Porphyra* appears to be an excellent choice for bioremediation of moderately eutrophic effluents, with the added benefit that tissue may be harvested for sale.

Keywords: Integrated aquaculture; *Porphyra*; Nutrient uptake; Nitrogen content; Bioremediation

1. Introduction

Finfish mariculture along the Northeast American coast continues to grow, however, there are some constraints (Naylor et al., 2000; Troell et al., 2003). On local to regional scales, finfish aquaculture may significantly contribute to the nutrient loading of coastal waters because of effluents rich in inorganic nitrogen (N) and phosphorus (P) (Kautsky et al., 1997). These nutrients derive from the bacterial release of inorganic N and P from non-consumed animal food, and from excretory waste products of the cultured animals (Beveridge, 1987; Chopin et al., 2001). The detrimental effects of eutrophication include blooms of harmful phytoplankton and unwanted macroalgae

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(Cuomo et al., 1993; Naylor et al., 2000), as well as development of hypoxia and anoxia (Bonsdorff et al., 2002; Sfriso et al., 1992). The ecological incentive for remediating eutrophic effluents through balance ecosystem management is clear (McVey et al., 2002). Besides this ecological aspect, there are also economic incentives. The N and P that are flushed from the system represent the loss of opportunity for the aquaculturist, since these nutrients could be channelled into the production of valuable products (Chopin et al., 2001). In addition, governmental agencies charged with reducing coastal eutrophication are developing regulations to limit the release of N and P. In the future, U.S.A. aquaculturists can expect to incur financial penalties if they cannot regulate the release of the waste effluent (Anonymous, 2002).

One solution to the problem of eutrophic effluent, addressing both ecological and economic issues, is the development of integrated aquaculture, in which seaweeds are grown downstream from animals (McVey et al., 2002; Chung et al., 2002). Systems of integrated aquaculture are ideal because the N and P in the animal effluent are necessary requirements for the growth of the seaweeds. This is not a new idea (e.g., Ryther et al., 1978). Previous studies have focused on the integration of other macroalgal species into finfish culture, as *Ulva lactuca* (Coen and Neori, 1991) and *Ulva rotundata*, *Enteromorpha intestinalis* and *Gracilaria gracilis* (Hernández et al., 2002; Martınez-Aragón et al., 2002). While these species may be efficient nutrient filters, the use of the harvested biomass is limited to organic composting and low-profit agar extraction. One thing that distinguishes this study from prior ones is the selection of the algal component. Obviously, the best seaweed to integrate into an animal aquaculture operation is one characterized by rapid growth, the accumulation of N and P to high levels in tissue, and some added value (Neori et al., 2004). We investigated the genus *Porphyra* as the seaweed component for a number of reasons. All species of *Porphyra* produce gametophytes that are flat sheets one or two cell layers thick. This combination ensures an extremely high surface area-to-volume ratio, with all cells involved in the uptake of nutrients and production of new tissue (Neori et al., 2004). In part for these reasons, *Porphyra* is capable of rapid growth. Species of *Porphyra* are also efficient nutrient concentrators. In situations where nutrients are readily available, N can constitute 6% of dry tissue biomass (Chopin and Yarish, 1998, 1999). Finally, several species of *Porphyra* form the basis for a multi-billion dollar (U.S.) global business in the production of nori for human consumption (FAO, 2003). Another added value development is the use of *R*-phycoerythrin as the fluorescent conjugate for immunological detection of target molecules in molecular biological research (Mumford and Miura, 1988). Several studies of native Northeast American *Porphyra* species have clarified the taxonomic status and ecological requirements (Klein et al., 2003; Neefus et al., 2002; Yarish et al., 1998), as well as their potential productivity (Kraemer and Yarish, 1999). The positive role of *Porphyra* in removing N and P in sites of experimental nori/salmon integrated aquaculture has also been reported (Chopin et al., 1999; McVey et al., 2002).

Growth, accumulation of N and P, and high value by-products in tissue are dependent upon the environmental factors that regulate production: temperature, nutrient availability, irradiance and water motion. As part of an effort to develop an economically viable system of integrated polyculture, we have been evaluating the bioremediation and mariculture potential of Northeast American and Asian species of *Porphyra*. We have included Asian species in the comparison since they represent in many ways the industrial benchmarks. However, we do not advocate the use of non-native species of *Porphyra* in open water culture. We present here results that describe the influence of N source and concentration on growth, nutrient uptake, *R*-phycoerythrin and tissue N contents.

2. Materials and methods

2.1. Plant material

Gametophytic blades of *Porphyra* species used in the experiments were generated from the conchocelis stage, after inducing the formation and release of conchospores. The experimental work was conducted under controlled environmental conditions of irradiance, temperature, and photoperiod in walk-in growth chambers at the Marine Biotechnology Laboratory of the University of Connecticut at Stamford. Under those conditions, both foliose and conchocelis phases of all the strains are maintained in continuous culture in von Stosch's seawater enrichment (Ott, 1965). The Northeast American species included *Porphyra amplissima* (strain ME32), *Porphyra leucosticta* (strain CT23-1), *Porphyra purpurea* (strain NY4-1) and *Porphyra umbilicalis* (strain ME6-9), while Asian species included *Porphyra haitanensis* (origin of strain unknown), *Porphyra katadai* (strain PKTF99) and *Porphyra yezoensis* (strain PYWT2001039A).