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Review: Production of *Gracilaria parvispora* in two-phase polyculture systems in relation to nutrient requirements and uptake

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Abstract *Gracilaria parvispora* Abbott is highly valued in Hawaiian seafood markets. Due to the over-harvesting of natural beds. *G. parvispora* is scarce on the open reef ; and harvesting is strictly regulated. On Molokai, Hawaii, a community-based operation was established to develop a sustainable, integrated culture system for this species. Previous research suggested that ammonium was the limiting factor for sufficient growth on the reef. Therefore, on Molokai, a polyculture system was developed using fish/shrimp effluent to load thalli with nitrogen before placement in a low-nutrient lagoon for grow-out. The research described here demonstrates how small-scale, commercial culture of seaweed can be successfully integrated with the production of fish and shrimp. Two benefits of a two-phase polyculture system are: 1) a waste product from the first phase (i.e. ammonia nitrogen) becomes a resource for the second phase and 2) integrated systems are financially more stable because of improved cash-flow and product diversification. A modest biomass of fish can support a substantial production of seaweed. The type of cage-based, polyculture system developed on Molokai could be applicable to other rural coastal areas.

Key words: *Gracilaria parvispora*, polyculture, tank culture, effluent, nitrogen

Introduction

Intensive tank and pond culture of free-floating seaweeds has been developed over the last two decades in Israel (Friedlander and Levy, 1995), Taiwan, Chile, the United States, Canada (Buschmann, 2001) and other areas. Advantages of these methods include a high potential yield, the possibility to control and mechanize operations and the possibility of using seawater ponds as biological filters for fish culture and other effluents (Friedlander and Levy, 1995). A disadvantage is the high cost compared to less intensive culture methods. However, on the island of Molokai, Hawaii, we have developed a two-phase polyculture system for production of seaweeds that has the advantages of more intensive culture systems but can be operated at low cost.

The integrated aquaculture system described here was designed as a model for sustainable, small-scale crop production in rural areas of the tropical Pacific. The research was initiated partly in response to declines in local seaweed resources in Hawaii, where seaweeds such as *Gracilaria parvispora* are valued, traditional foods. In Hawaii, over-harvesting of *G. parvispora* from the fringing reefs started in the 1970s, and this led to a severe decline in natural stocks. As a result, conservation laws

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have been enacted that limit wild-crop harvesting; and commercial harvesters cannot take more than 4 kg per day. In addition, it is forbidden to remove cystocarpic thalli from the water. The initial restoration project, whose purpose is to develop a cultivation system to re-establish *Gracilaria* on the reef, was instituted as a result of declining wild stocks.

The project was developed in conjunction with a non-profit, community-development organization on Molokai. The group, Ke Kua'aina Hanauna Hou (KKHH), was established in 1991 to develop ways to help the local community by developing means for individuals or groups to earn an income while maintaining the local land-use traditions. Although they participate in the modern economy, many Molokai families still derive a substantial percent of their livelihoods from fishing, gardening, and other subsistence activities that help them maintain a connection with their traditional value system, including a sense of stewardship towards their island's natural resources. Marketing seaweeds is one way for native Hawaiians to achieve this.

In Hawaiian seafood markets, an edible, red seaweed *G. parvispora* known locally as "long ogo" is highly valued (Glenn *et al.*, 1998). Total sales of *G. parvispora* by KKHH in 1999 were 10,670kg with a wholesale market value of approximately $75,000. By combining ogo culture with shrimp and fish culture, production has increased substantially. Molokai long ogo sells for $7 per kg (a $2.20 per kg premium over other seaweeds on the market), and sales of Molokai ogo was approximately $250,000 over the last 12 months.

In previous work, Glenn *et al.* (1998, 1999) demonstrated that *G. parvispora* is limited by nitrogen on the south reef of Molokai, HI. This led to the development of a labor-intensive culture system where the seaweeds were produced in cages in the nutrient-poor coastal area and then brought in each week to be fertilized in tanks. More recently, the production system was modified to reduce labor and increase yields by integrating the cage grow-out system with the local production of fish and shrimp, which are examples of other small-scale commercial aquaculture enterprise that have developed on Molokai.

The environmental benefits of integrating the production of aquatic plants with the production of fish or shrimp to recapture nutrients are well known (e.g., Buschmann *et al.*, 1994; Neori *et al.*, 1996; Shpigel and Neori, 1996; Chopin and Yarish, 1998; Mathias *et al.*, 1998; Troell *et al.*, 1997, Petrell *et al.*, 1992.). Most of the research on integrated plant-animal aquaculture systems has involved intensive, land-based culture methods (Buschmann, *et al.*, 1994; Neori *et al.*, 1996; Shpigel and Neori, 1996). Growing multiple cash crops such as shrimp, fish, bivalves, and seaweeds in extensive systems is common in Asian aquaculture systems (Chen, 1990), but this has not been widely adopted in western aquaculture.

The focus of this paper is to describe the application of this concept to the development of a two-phase polyculture system that has been successful on Molokai and could therefore serve as a model for similar small-scale commercial development in other tropical areas.

The Molokai two-phase polyculture system

Since 1992, the University of Arizona together with Ke Kua'aina Hanauna Hou worked at developing and refining a community-based system for culturing *Gracilaria*. The system now incorporates: a hatchery (Nelson and Glenn, 2000), which produces spore-coated substrates for distribution to outside growers; outplants of sporelings on the reef or in polyculture with fish and shrimp; a cage-culture farm for multiplication of the harvest; and a processing facility. The two-phases of seaweed culture in this system are an enrichment phase and a grow-out phase (Fig. 1). The overall method involves all the life stages of the seaweed crop and enhances wild stocks on the reef. The system incorporates the major strategies of ecological design: conservation, regeneration, and stewardship (Van der Ryn and Cowan, 1996).

From research in outplanting of spore-laden materials it was found that the success of sporeling development was related to dissolved ammonia levels in the immediate vicinity (Glenn *et al*, 1999). This led us to look at growing the seaweeds in conjunction with fish or shrimp, since the primary excretory product of aquatic animals is dissolved ammonia. Our first trials involved marine shrimp culture, because one of the local shrimp farms was found to have dense populations of *G. parvispora* growing in its effluent ditch. We transferred nutrient-depleted, tagged thalli to the ditch and monitored their growth and nutrient content along with levels in the effluent (Nelson *et al.*, 2001). Because of the periodic draining of shrimp ponds into the ditch, nutrient levels fluctuated widely from day to day, but mean ammonia levels in the ditch (approximately 62 mmol m^{-3}) were many times higher than in nearby coastal waters. In this environment the thalli nitrogen content was increased from approximately 1 % to 3 % within about 5 days. We also found that when these thalli were placed in the lagoon for grow-out they grew at rates of 8 % to 10% per day for the first week. Growth and thalli nitrogen content declined over the 4-week growth period so that by the fourth week, growth was approximately 2 % per day and the nitrogen content was back to 1 %. Growth rates of thalli that were enriched in the ditch are shown in Fig. 2. This method of enriching the thalli requires much less labor than the weekly use of chemical fertilizers in tanks as was previously practiced.

Seaweed produced in the shrimp effluent channel became an important source of new material for stocking grow-out cages in the lagoon. Harvested seaweed from the ditch was not directly marketable because of heavy loads of sediment and epiphytes. However, after a period of grow-out in which seaweed biomass was increased in clean water, the product was of high quality and easily sold in local markets.

Success with the use of shrimp effluent led us to establish a tank culture system for production of local fishes at the seaweed production site (Nagler *et al.*, 2003). This allows more control of the production cycle and further decreases labor, by eliminating the need to

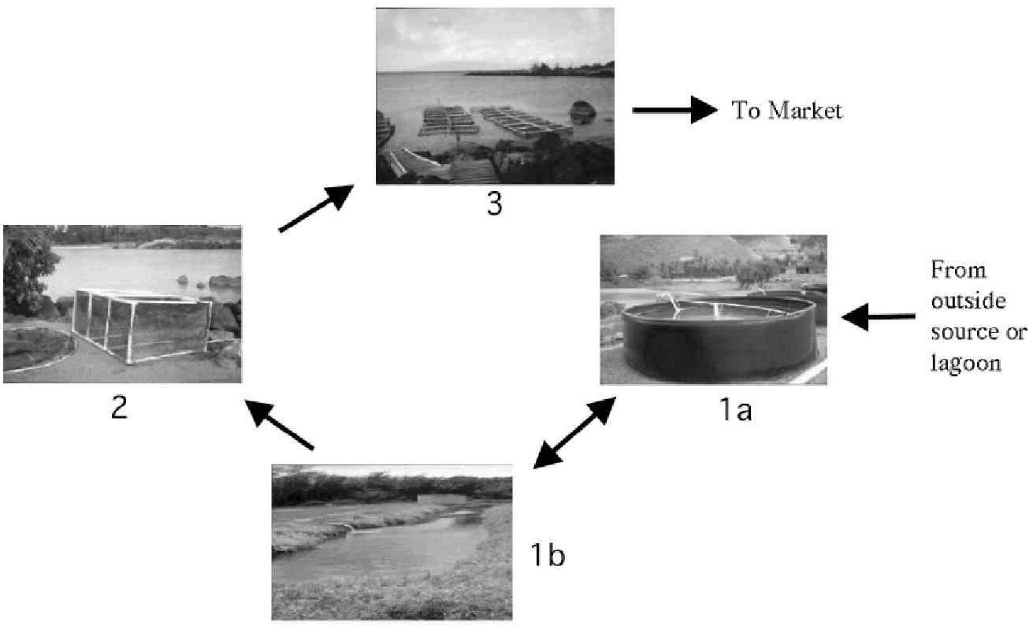

Fig. 1. Schematic of Ke Kua'aina Hanauna Hou's polyculture system for production of *Gracilaria* parvispora. Seaweed is supplied by outside growers or hatchery then fertilized in shrimp/fish effluent channels (1a, 1b). After enrichment with nitrogen, the seaweed is placed in floating cages (2) and floated in Puko'o lagoon for growout (3). After 10 days in the lagoon, the seaweed is cleaned and sold to market.

harvest seaweed from the effluent ditch and transport of the harvest to the grow-out facilities. Milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) juveniles were obtained from the Oceanic Institute on Oahu and were cultured in tanks onshore immediately adjacent to the seaweed grow-area. Milkfish grew much better in the tanks than mullet and is now the primary species being cultured.

Nagler *et al.* (2003) were able to densely stock the fish tanks with nutrient-poor seaweed for periods of 7 days in order to enrich the thalli. Over the enrichment period the thallus nitrogen content increased up to 5 % on a dry weight basis. The growth rate of enriched thalli was up to 10 % per day and production in the cages ranged from 39-57 g dry mass per m^2 per day over a 21-day production cycle. In these trials with fish, we estimated the nitrogen requirements of *Gracilaria* and calculated the amounts of fish feed needed to provide these amounts, without calculating the actual excretion rates of the fish. Subsequently, however, in order to provide data useful in designing a similar integrated farm, we measured the excretion rates of fed milkfish as the amount of nitrogen excreted per gram of fish.

For the excretion studies (unpublished), milkfish of various sizes were held individually in 55-L, aerated tanks that were filled with seawater from the grow-out site on Molokai. Water samples from the tanks were taken immediately after the fish were added and at 2-hour intervals thereafter. We used a fluorometric method for determining the concentrations of dissolved ammonia (Holmes *et al.*, 1999). Data for the first 2-hour period are shown in Fig. 3, which shows the relationship between fish mass and the ammonia excretion rate in a log-log plot. Mean excretion rates were 7.03, 2.17, and 1.81 μg g^{-1} per hour for mean fish weights of 200 g, 800 g, and 1200 grams, respectively.

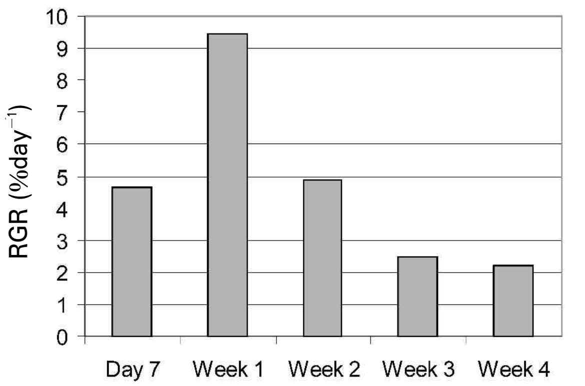

Fig. 2. *Gracilaria parvispora* relative growth rates (RGR) after enrichment in a shrimp effluent channel. Day 7 growth rates occurred during the enrichment process. Week 1 depicts growth after placement in lagoon. Seaweed experienced initial rapid growth during the first week, then lower growth on subsequent days. Data are from Nelson *et al.* (2001).

Projections

Data from these studies was used to calculate the fish biomass required to support the seaweed production levels usually achieved at the Molokai grow-out site. This is a small-scale cage culture operation that typically has about 80 cages in production throughout most of the year. The optimal stocking density for the cages, in terms of the percent increase of seaweed biomass, was determined to be approximately 2 kg per cage (Nagler *et al.*, 2003). Table 1 shows the requirements of the biomass and number of fish needed to support a variety of seaweed production projections. As shown, even at high stocking densities, the amount of fish needed to support *G. parvispora* growth is relatively small. Considering KKHH is a small,

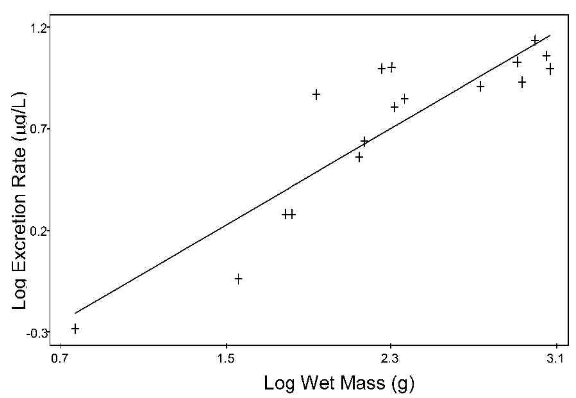

Fig. 3. Relation between wet fish biomass and excretion of ammonium (μg/L).

Table 1. Number and biomass of milkfish required to support (to increase nitrogen content of thalli from 1 to 4 %) the production of Gracilaria parvispora in a two-phase polyculture system in Hawaii

Total algal biomass	0.2-kg fish		0.8-kg fish		1.2-kg fish	
(kg wet weight)	kg fish	# fish	kg fish	# fish	kg fish	# fish
40	17	85	55	70	7	57
80	34	170	110	140	133	115
160	68	340	220	275	265	230
320	140	680	440	553	530	460
640	270	1,365	885	1,106	1,060	917

community-based operation, they can sufficiently support their ogo production using fish effluent as a nutrient source. Their current operation consists of several tanks containing enough milkfish to enrich the seaweed that is in the production system.

Conclusions

The production of *Gracilaria* in cage culture can be successfully integrated with small-scale production of fish and shrimp. Seaweed stocked in shrimp culture effluent ditches can thrive with little management and can serve as stocks for grow-out in clean, low-nutrient water. We were able to achieve similar enrichment of *Gracilaria* thalli by holding stocks for 5 to 7 days in fish tanks. We found that a even a modest biomass of fish can support a substantial production of seaweed in this culture system. This was also the case in studies of *Gracilaria* cultivated with salmon grown in cages (Troell *et al.*, 1997; Buschmann *et al.*, 2001), where increased productivity of 1 hectare of *Gracilaria* could be supported with 5 % of the fish dissolved nitrogenous waste. In the culture operation on Molokai the main benefits of nutrients are to support seaweed production rather than to scrub nutrients for effluent. However, if seaweeds are cultured on a larger scale, such as for the phycocolloid industry, they can be efficient at removal of nutrients from effluent of intensive land-based fish farms (Troell *et al.*, 1997; Chopin *et al*, 2001).

Disregarding the environmental benefits of integrated seaweed and fish or shrimp production, seaweed culture can also benefit small-scale aquaculture farms by increasing their economic viability. Small aquaculture enterprises for shrimp or fish, such as those on Molokai, tend to be financially unstable, because they have continuous, fixed expenses but intermittent income because their harvests come in batches that are spaced weeks or months apart. Integration of seaweed production with these systems greatly improves cash-flow, as seaweeds can be harvested weekly throughout the year. The seaweed component in our system is worth approximately $7 per kg and revenues from seaweed sales could significantly enhance the profitability of an integrated system. On Molokai, the use of fish or shrimp effluent increased production of *Gracilaria* and also resulted in reduced labor requirements, an additional economic benefit. In addition, diversification of farms in the community can aid in reducing competition and stimulate the formation of cooperative relationships among producers. This type of cage-based, polyculture system developed on Molokai could also be successfully employed in other rural areas of the Pacific.

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