AGRO-ENVIRONMENTAL TECHNOLOGY GRANT PROGRAM

FINAL REPORT

Greenhouse Polyculture System

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ABSTRACT

Coonamessett Farm received an Agro-Environmental Technology Grant from the Massachusetts Department of Food and Agriculture to design and build a greenhouse based polyculture system. The design is built around ten thirty-two square foot tanks supported on a bench with all the associated mechanical and controlling hardware. The prototype system can be used in three different growing modes; ebb and flow, nutrient film, and continuous holding. The ebb and flow mode is used primarily for watering potted plants for garden sales and consists of flooding and draining the table tops on a timed cycle. The mode involving the nutrient film technique (NFT) is a hydroponic growing strategy where a continuous stream of nutrient solution is pumped passed the roots of the crop. The continuous holding mode entails holding a tank top water level from two to ten inches either with or without recirculation. This mode can be used for float system hydroponics and/or aquatic species holding. The initial crop tests included growing salad mix and holding crayfish.

INTRODUCTION

Coonamessett Farm is a twenty acre farming and research enterprise located on Cape Cod. Crops include small fruit, vegetables, bedding plants, and flowers. Research and technical consulting services are offered in small scale agriculture, aquaculture, and fisheries. Over time two key observations have been made by Coonamessett Farm personnel. The first is that there are periods of time that expensive greenhouse space and equipment remains underutilized. This is because it is either a period between crops or the value received for the crop at that time is low. The second observation is that there is a great deal of similarity in equipment developed for greenhouse production of crops and that used for aquaculture. This lead to the belief that one set of equipment might be capable of accomplishing multiple growing strategies.

This project was designed to demonstrate the commercial viability of using available greenhouse plant growing systems and aquaculture systems for the production, holding, and marketing of multiple terrestrial and aquatic crops. The goal is to employ permanent farm labor and farm equipment during off-peak greenhouse production periods. In addition, as part of this project, a new technology from Japan called Bio-Cord, was demonstrated. Bio-Cord can be used to maintain water quality in aquatic growing systems and other places on the farm.

Many small farms and nurseries in Massachusetts now have greenhouses to start field transplants, to grow seasonal bedding crops, to grow hydroponic crops for market, and to extend the season of traditional field crops. Coonamessett Farm typically performs all of the above activities. In 1996, Coonamessett Farm received an Agro-Environmental Technology Program Grant to demonstrate year-round production of salad greens in a ground heated greenhouse. The lettuce and greens, both for this greenhouse and field production, are grown as transplants in plastic containers using soilless mix in a conventional greenhouse. The plastic containers are recycled by washing and disinfectant; a time consuming labor intensive task. The soilless mix is not an inexpensive input either.

Coonamessett Farm started to produce transplants on a limited basis in small oasis cubes using hydroponic concepts. A new product line was created at the request of restaurants; miniature heads of lettuce. The success of these endeavors lead to the examination of the possibility of expanding hydroponic transplant/mini-lettuce production. However, salad greens are sold by the pound and hydroponically produced lettuce and greens tend to be very light when compared to field grown product. In addition, greenhouse hydroponic greens do not have the variety of flavors and textures of field produced greens which chefs prefer. Since chefs prefer field grown greens when available it is not economical to set up an expensive hydroponic system solely for off season production of this product.

Coonamessett Farm investigated purchasing ebb and flow bench systems as a means to hydroponically produce transplants as well as spring bedding plants. Ebb and flow systems have many advantages including significant time savings compared to hand watering. From an environmental standpoint most greenhouse operations may ultimately require them since these recirculating systems completely eliminate chemical runoff. Water use in these systems has been reported to be cut by two-thirds and fertilizer use by up to three-quarters (Josko, 1991). Interestingly, with some modifications, ebb and flow bench systems can be used to grow aquatic crops such as ornamental fish, crayfish and bait fish (golden shiners, fathead minnows, goldfish, etc). Many garden centers are now selling aquatic gardens and ornamental fish for the rapidly expanding water garden market. Baitfish and crayfish are in high demand as bait for fresh water fishing. In addition, some restaurants are interested in trying crayfish as a substitute for expensive shrimp on the menu. The demand for crayfish is increasing both domestically and overseas (Ladewig and Schaer, 1993).

Coonamessett Farm proposed to set up a modified ebb and flow system that can be used to demonstrate the commercial viability of raising greenhouse crops (bedding plants and field transplants) and aquatic crops (crayfish, baitfish, ornamental fish) with the same equipment. The primary modification being higher and stronger sides on the ebb and flow tables to contain higher water levels. Feasibility of growing crayfish in a greenhouse environment in shallow trays has already been demonstrated (Culley et al, 1985). Initially the plan was to stock the system with commercially available crayfish and/or baitfish but ultimately to capture and raise native Massachusetts species.

Bio-cord technology was tested as a means of maintaining water quality in the closed system. The cord is basically a core covered with many rings of thread that provides a large surface area for the attachment of microbes (see attached addendum). Interestingly, crayfish and baitfish feed on micro-organisms. Besides maintaining water quality, the presence of the Bio-Cord may provide an alternate food source for the aquatic crop.

The plan was not to raise the green and aquatic crops simultaneously but in a rotational manner. This was to avoid the problems associated with trying to integrate different growing requirements. Crayfish can easily be integrated into agricultural crop rotation (Bretonne and Romaire, 1990) and grown simultaneously with baitfish (Alon and Dean, 1985). The idea is to expand and diversify production from the same capital investment, thus creating more profit, in an ecologically sound manner. Ebb and flow systems are totally self-contained and require less input of fertilizer, water, soilless mix, and plastics than other conventional plant production systems. The cross-fertilization of technologies between agriculture and aquaculture will promote the application of these technologies and create new capital investment.

In summation, most small farms and nurseries in Massachusetts have greenhouses and growing systems that are not set up to recirculate water thus there is the risk of groundwater contamination by fertilizer and chemical runoff. At a minimum, there is a higher use of water and fertilizer inputs than in a closed system. If it can be demonstrated that there is more potential income from multiple uses of closed systems as identified in this project then the public benefits of groundwater protection and small farm/nursery viability (open space preservation) can be achieved.

Objectives

1. To compile information on the culturing requirements for crayfish, baitfish, and ornamental fish in order to specify holding system criteria.

2. To assemble a modified ebb and flow bench system that can meet aquatic holding system requirements and to instrument the system for the collection of operating data, ie, water quality measurements.

3. To produce a plant crop, followed by an aquatic crop, followed by another plant crop, during the course of a season maintaining complete growing and marketing records.

4. To utilize the Bio-Cord in a controlled experiment in the system to determine the product's impact on water quality maintenance.

5. To demonstrate the Bio-cord in a cranberry bog setting to determine the product's impact on water quality. Crayfish and/or baitfish were to be utilized as part of this test.

6. To write a report completely documenting the project's results.

CULTURING REQUIREMENTS

A literature search was conducted on culturing crayfish, baitfish, and ornamentals though we concentrated on crayfish. Over fifty references have been copied and evaluated resulting in a general specification of our holding system. The following is a brief summary of the results of the literature search.

Crayfish

Native Massachusetts crayfish may be a good choice for diversifying existing fresh water aquaculture ventures, cranberry operations, and greenhouse plant production facilities. They grow fast, reproduce rapidly, and are very tolerant of low water quality. Crayfish can be marketed live as a gourmet food, bait, and as pets. They can be grown in conjunction with terrestrial and aquatic plants, bait fish, and ornamental fish. The species this project focused on was the white river crayfish, *Procambarus acutus*. This species has recently been renamed as *Procambarus zonangulus*. The high abundance of this crayfish in Southeastern Massachusetts cranberry bogs, streams, and ponds indicates that there is significant potential for culturing this species in large quantities that could have significant and positive economic impact. Massachusetts enjoys significant advantages over southern producers because of the proximity to potential high value markets.

Crayfish are commercially produced in the USA by establishing perpetuating populations in ponds or rice fields. There are a limited number of semi-intensive growing systems used for either raising juveniles for pond stocking or for producing soft-shell crayfish using pond stock. There is also an increasing demand by the aquarium trade.

One potential market is the fish bait trade. Small crayfish, 2.5-3.5 cm (1-1.5 inches) make excellent bait for yellow perch and bluegill sunfish. Larger crayfish, 2.5-3.5 cm (1.5-2.5 inches) have a reputation as great bass bait. The price range for crayfish as bait is dependent on size. Prices run between $0.25 and $1.00 each. Another potential market is soft shell crayfish for the white tablecloth restaurant trade. These crayfish, about 30 to the pound, receive farm gate prices of about $6.00/lb and retail to the restaurants at $11.00/lb. The desirable market size for hard-shell crayfish is about 30 grams.

Culturing crayfish requires an understanding of how to keep crayfish alive and growing. In some cases the culturist will also want to have crayfish successfully reproduce. Crayfish increase their size by molting. The rate at which they grow is dependent on how often they molt and the size increase at each molt. Factors that affect growth include water temperature, water condition, photo period, nutrition, crowding, and stress. It is assumed that improved conditions of space, feed, and water quality should greatly enhance growth compared to the wild.

Optimum temperature for the species of interest in this project, *Procambarus acutus*, is from 20-25 degrees Celsius (68-77 F). It is possible that this species held in this temperature range during long-day photo periods could molt every 6-10 days and reach lengths of 75 mm in three months.

Other water quality parameter recommendations for crayfish are dissolved oxygen greater than 3 ppm, total hardness greater than 100 ppm, pH from 6.5 to 8.5, carbon dioxide less than 5 ppm, and ammonia less than 1 ppm. Water hardness of 100-150 ppt has been recommended for pond culture. Calcium uptake is impaired when pH is below 5.75.

Crayfish are opportunistic omnivores; they will eat most anything. Most of their diet in the wild is believed to be microbially enriched detritus. Macro invertebrates and seeds may be important food sources in the wild as well. Crayfish need calcium to grow which can be supplied from the water or from the feed. Sinking fish pellets are suitable for feeding crayfish however they rapidly disintegrate in the water requiring close attention to maintenance of water quality. Feeding rates should be about 3% of body weight for growing juveniles and about 1% for adults. In the cold winter months feeding can be reduced. High protein (40 percent) floating trout pellets have been used in shallow water holding tanks at the rate of 3-4 pellets per crayfish. There is still considerable discussion on what is the best diet to maximize growth in crayfish. Some studies suggest zooplankton is very important for juvenile growth. *Daphnia* as a feed has been shown to cause considerable weight gain in crayfish compared to plant-based feeds. Population density is the most important factor for limiting growth in crayfish.

Bottom cover and shelter are important to the growth and survival of crayfish. It has been reported (Brown et al, 1995) that stocking densities above 5 individuals per square meter results in significant mortalities. In intensive culture systems shelter has been shown to increase the survival of crayfish, but not growth, with stocking densities of 20-25 crayfish per square meter. Survival was depressed with stocking densities of 100 per square meter. Growth and survival can be increased by layering the tank bottom with window screening or onion bags.

North American crayfish species exhibit significant resistance to disease. There are few disease or parasite problems associated with their culture. However, high mortality has occurred in earthen ponds and confined holding systems from vibriosis.

Breeding

Density of brood stock should be about one to two animals per square foot of tank (8-20 per square meter). Sex ratio of 1:1 is desirable. Water depth does not need to exceed 6-8 inches. Feeding should be minimal to preserve water quality. Water exchange/replacement can be minimal. Raising water temperature in January-February can induce egg laying and hatching up to three months earlier than in the wild.

The red claw crayfish, *Procambarus clarkii*, is the better known southern cousin of the white river crayfish. Red claw females lay their eggs within 2-8 weeks of copulation when water temperatures are around 22 degrees C (72 F). The eggs are extruded onto the swimmerets and take a couple of days for the attachment to firm. The berried females than can be held individually or in communal tanks with plenty of shelter. The young crayfish when hatched can be held at densities of 9-18 per square foot (100-200/sq m) for about a month.

Soft-shell Production

Crayfish, after molting, have a soft-shell stage that lasts for about 12 hours and a papershell stage that lasts 36-48 hours. Soft-shelled crayfish have a much higher market value than hard-shelled crayfish both as a food item and as bait. Soft-shell crayfish can be almost entirely eaten compared to only the 12-15% of the tail meat of the hard shell animal. Red swamp crayfish have been the most suitable for soft-shell production; white river crayfish do not do as well in shedding systems down south. The soft-shell crayfish production industry, for the gourmet food market in the southeastern states, has not shown itself to be economically viable due to high production costs.

Crayfish can be held in shallow tanks for the purpose of harvesting and selling the newly molted soft-shell animal. Research in Louisiana focused on this technique in the 1980's. Stocking densities of small (<2 in) pre-molts initially did not exceed four animals per square foot. Larger crayfish (3-4 inch) were stocked at densities of about one per square foot of tank bottom. More recently stocking densities of 24-30 crayfish (about 1 lb) per square foot of tray surface has been used successfully. The tanks should be light colored and well lighted for ease of identifying molting crayfish. The sides of the tanks need to be at least six inches high to prevent the crayfish from escaping.

The Louisiana system, set up in a 35 x 96 greenhouse uses trays that are 3 feet wide by 9 feet long placed about 30 inches above floor level. Water flow rates were 15 gallons an hour. The tanks held 2 inches of water, about 40 gallons, thus there was a complete water exchange every 3 hours. Partitions were used in the tanks to separate the crayfish for easy inspection. Two foot square sections held up to 40 crayfish and inspections for molts were conducted at 12 hour intervals.

Systems have evolved to where a typical operation might operate 48-60 trays, 8 feet by 3 feet with water depths of six inches. The trays, when used for shedding, have water levels of only ½ to 1 inch maintained by spraying the water over the crayfish. Water flows of 1 to 3 g.p.m. are enough to maintain dissolved oxygen levels above 5 mg/l and ammonia below 0.5 ppm. The trays are tilted so the water flows out one end through a screened outlet. It has been found that 90% of the molting takes place during daylight so frequent inspections are made during the day to harvest the freshest molts.

Baitfish and Ornamentals

Freshwater finfish culture can be either integrated with hydroponic plant production or conducted in rotation using the same facilities. Integrating the fish culture and plant production has many additional problems associated with the process than when performed separately. In Louisiana, research has been conducted on using soft-shell crayfish production facilities, during the off-season, to hold and raise koi carp and goldfish. Finfish and crayfish can be cultured together but there are some additional management problems related to water depth and disease.

The Coonamessett Farm polyculture system design includes the ability to hold small finfish species such as baitfish and ornamentals. This category includes golden shiners (*Notemigonus crysoleucas*), fathead minnow (*Pimephales promelas*), goldfish (*Carassius auratus*), and koi carp (*Cyprinus carpio*). These species are regularly grown in intensive culture and have well developed feeding programs. This project did not focus on breeding requirements for these species.

There are several additional requirements for small finfish holding that are not needed for crayfish. Additional sources of water aeration would be very useful to insure against oxygen depletion. Automatic feeders would be essential to avoid the need for frequent hand feeding. There also needs to be more effort expanded to filter out particulate matter to prevent ammonia toxicity.

SYSTEM DESIGN

The specification can be broken down into several design areas; bench structure, table top, monitoring system, circulating system, and auxiliary equipment.

Facilities

The modified ebb and flow system was installed in an existing 30' x 96' greenhouse on Coonamessett farm. The greenhouse is heated by a Seibring Model OT210 oil heater controlled by a Dayton single stage thermostat. Ventilation is provided by two 48-inch fans and two thermostatically controlled shutters. The greenhouse is covered with doubled poly and the floor consists of gravel. The water supply is from a well.

Bench Structure

Two greenhouse suppliers of bench systems were contacted and both had concerns about the amount of bench loading full tank tops would exert. The design load specified was one cubic foot of water per square foot of bench area (65 lbs/sq ft). These manufacturers were not interested in modifying their systems (designed for a maximum of 25 lbs/sq ft); they proposed significantly increasing the number of bench legs and bench top crosspieces as a solution to the load problem. The costs associated with this approach quadrupled the bench price from $1000 up to $4000 approximately.

We then proceeded to contact Unistrut, a manufacturer of modular steel support systems. The specified bench loading was even high for this system thus requiring many braces, legs, and cross pieces at a price comparable to the greenhouse bench manufacturers. Next, we investigated the use of Speed-rail fittings, and found that the bench could be constructed for about $2000 out of these slip-on fittings and 1.25-inch inch galvanized steel pipe. In fact, it would be much less expensive to build standard greenhouse benches using this approach compared to marketed greenhouse bench systems for the same design loads. We ordered the bench system fittings, including pre-cut galvanized pipe, and erected it on June 18, 1997. The assembly took two men about eight hours.

The tank builder recommended that the bench have a continuous solid top so the bench was covered with three-quarter inch plywood supported by 1 x 4 cross-pieces on 24-inch centers laid flat. The top was secured to the steel bench by the use of galvanized pipe clamps. This is not an optimal design but it works. In the long-term builders may want to consider a closely spaced galvanized steel cross section (ie, square tubing) to support the tank tops.

Table Top

The next major design area was the bench top. This design was driven by the need to hold at least eight inches of water for aquatic species. A twelve inch tank depth was chosen to allow for additional flexibility. The tank width of 48-inches was a compromise between the three proposed uses. The tank length of 96-inches was flexible. We investigated conventional ebb/flow bench tops and found that the Danish manufacturer would glue an extra side wall to their system but the shipping costs were high and we were not sure of the strength for our aquatic application. We contacted over a dozen manufacturers of plastic tanks, and investigated the construction of plywood tanks. Prices ranged from $400-700, including freight charges, for a 12" x 96" x 48" fiberglass tank. Finally we found a boat builder in Rhode Island that had a mold for a worm growing tank that met our need. He was willing to supply the tanks at his construction cost ($225.00) because of his interest in aquaculture applications. We ordered ten tanks that arrived June 9, 1997.

The tank top consists of ten fiberglass tanks. The tanks have been piped together in two systems. Each system has two under-bench holding tanks. One holding tank contains the Bio-Cord filter and is connected to the second tank that contains the pump. A U/V sterilizer has been connected so that it can be placed in-line with either system. One system has been set-up for hydroponic lettuce production and the other for holding crayfish. The tanks are blocked up slightly on the inlet side to allow for easy draining during cleaning.

Monitoring System

We investigated the use of existing greenhouse and aquaculture monitoring systems. The inexpensive greenhouse systems do not have the capability to monitor all the parameters we were interested in observing. Continuous automatic data logging was accomplished with an Aquadyne Octopus 3000 environmental controller. Parameters measured were water temperature, ph, and conductivity. The system also has the potential to measure oxidation reduction potential (ORP). The unit can hold up to seven days of data, can activate electric controls, and send alarms. The unit can also be attached, via remote access, to a computer for downloading of data or continuous monitoring.

Two water test kits were acquired to monitor additional water quality parameters. The hydroponics test kit is used to measure pH, nitrate nitrogen, ammonia nitrogen, phosphorus, sulphate, calcium, magnesium, and potassium. The freshwater test kit is used for detecting lower levels of nitrogen and ammonia, alkalinity, carbon dioxide and hardness. An electronic test pen was used for routine checking of pH and conductivity (EC).

Circulating System

We have found that all the circulating system equipment is readily available from either plumbing, greenhouse or aquaculture suppliers.

The circulating system was installed and is operating quite well. Five tanks are on hydroponic mode and five tanks are on aquatic species holding mode. Both modes are similar except for the water depth in the tanks and flow rates. In each system the water flows from a 1200 gph submersible pump, in continuous operation located in the holding tank, either through a recirculating line or an electrically controlled valve to the tank inlets. The recirculating line can pass through the U/V sterilizer and back to the filter tank. This line also contains a venturi that aerates the water and/or injects ozone from the ozone generator on the sterilizer. The tank inlets contain manually controlled valves to adjust the flow rates. The outlets of the hydroponic tanks contain stand pipes to keep the water level at two inches; the aquatic species tanks have stand pipes that maintain eight inches of water. The hydroponic tanks contain sheets of foam with holes for plastic net baskets. Lettuce has been started in oasis cubes and will be placed in the net baskets. Additional aeration will be provide by a separate blower supplying air stones in each tank.

Bio-Cord Filters

The Bio-Cord, a man-made Bio-Reactor, was tested in within the polyculture system. Racks containing the Bio-cord were constructed of PVC and placed into the filter tanks under the bench. Additional racks were also constructed for placement in bogs of cooperating cranberry growers (spring, 1998). An Appendix to this report contains the manufacturers literature concerning the bio-cord. We were not able to conduct a controlled experiment of the Bio-cord filters because too many variables were uncontrolled during this design period.

CROP PRODUCTION

Hydroponic production

Five tanks, referred to as System One, were placed into the hydroponic operational mode. Each tank is outfitted with an outflow standpipe that maintains a nutrient solution level of two inches. The nutrient is constantly being recirculated so that the exchange rate is about once per hour. Each tank has two sheets, 2' x 4', of one inch thick Styrofoam floating on the nutrient solution. Each piece of foam has 36 holes for plastic mesh pots on eight inch centers allowing for 72 planting sites per tank. Four tanks were stocked with lettuce (288 plants) transplanted in oasis cubes and one tank was stocked with opal and green basil plants (36 of each plant). Initial stocking took place on September 6, 1997.

The nutrient solution is a standard solution recommended by Peters. The mix for 100 gallons of solution consists of 5-11-26 Hydro-Sol (13 oz), 15-0-0 Cal-Lite (9 oz), and 10-0-0 Magnitrate (6.5 oz). The EC level of the components is 0.98, 0.74, and 0.34 respectively for a total EC value of 2.02. The EC level and pH are measured using a Hanna Instruments Agritest pocket pH/EC pen. Calibration is routinely checked with test solutions provided by Hanna. The measurements are recorded and can be found on the attached Polyculture Project Log.

In the first four weeks of operation the pH values were found to fluctuate considerably and dropped quite rapidly. We tried to buffer this movement by adding ground limestone which seemed to help reduce the fluctuations and rate of pH decline. However, as the Bio-Cord filter began to age and get covered with algae the system pH stabilized. We do not know if there is a correlation here but plan to research this aspect of system operation in the future. Unfortunately, we did not have the continuous monitoring system on line during the early stages of the project because of problems related to wiring in the greenhouse (GFD breakers tripping). Daily and weekly water testing showed non-detect for the parameters that would indicate filter performance such as nitrites and ammonia.

In the first six weeks of operation we harvested 97 pounds of lettuce leaves from the 128 square feet of growing area. These leaves were placed into our Coonamessett Farm salad mix. This mix retails between $4.00 -$6.00 per pound depending on package size. In addition we harvested several pounds of basil tops that were also used in our packaged salad mix. Roughly speaking this translates into about one dollar per square foot per week of production in this seasonal period. It would be interesting to compare this cut-and-grow-again production strategy with head lettuce production.

Crayfish operations

Five tanks, referred to as System Two, were set up in an aquatic species holding mode. The water level is maintained at eight inches by the use of stand pipes on the tank outlet drain hole. The water is constantly recirculated with an exchange rate of once every four hours. The U/V sterilizer is currently on line in System Two treating water recirculated from the pump back to the filter tank. A Bio-cord filter with 20 meters of material is located in the filter tank.

On September 26, 1997, 72 crayfish were captured by Linda Rinta in her Weweantic cranberry bog. The crayfish were apparently migrating from the bog into a marsh area. We have identified the crayfish as *Procambarus acutus*; commonly called white river crayfish. Additional crayfish were captured during a two week period bringing the total to 173. The lengths and tank distribution of the crayfish are given in the attached appendix table.

The crayfish were initially being maintained on a diet consisting of greens, dried dog food, trout pellets, chicken feed, and assorted other food stuffs. We located a source of inexpensive sinking fish feed which became the primary feed from December to the present. Less than 50 grams per week were being fed to the entire crayfish population over the winter months. Activity started to pick up in March and feeding was increased to 50 grams per day. The crayfish were observed molting and mating frequently through December and this activity resumed in March. A pre-molt crayfish is usually very dark in color. Just before molting the crayfish lays on its side. The shell splits between the carapace and tail and the crayfish exits the old shell.

We have placed into the tank a number of structures to provide shelter and hopefully to reduce lethal interactions between the animals. The structures include sections of PVC pipe and inverted 1020 plant trays.

We have found potential markets for the crayfish as food, bait, and as pets. We received a Class 3 Aquaculture Permit for a Type A Facility that initially only listed golden shiners since crayfish are unregulated. However, this became a Catch 22 because we could not sell crayfish without an aquaculture permit (buyers were uncertain of the legality). Finally, the permit was modified to list crayfish to overcome potential problems.

ECONOMIC EVALUATION

It is difficult to conduct an economic evaluation of the Coonamessett Farm polyculture system at this time. Most of this project was focused on designing and constructing the polyculture system and demonstrating its operation. We have crop data for the production of salad mix from October through early March. This is one of the most difficult growing seasons for this crop due to light limitations and heating requirements.

The system proved that it can hold crayfish through this period but no economic analysis is possible for evaluating crayfish as a crop. Research in Louisiana on soft-shell crayfish production systems indicated that 1440 square feet of tank space can produce about $13,252 worth of crayfish in four months ($6.00/lb base price). This is about 2200 pounds of crayfish which at 30 count means upwards of 65,000 crayfish were processed through the facility (about 20,000 at any one time). This type of system requires a continuous source of pre-molts. Crayfish are then sold through middlemen who receive $11.00/lb at the restaurant door. Our conversation with chefs on Cape Cod lead us to believe that $8.00/lb would be an acceptable delivered price for gourmet quality soft-shells. If a demand develops this could go higher.

However, we are uncertain to the quantity of crayfish that would be available for holding for soft-shell production and of the sourcing problems. We thus took a more conservative approach assuming that a one-time load of crayfish would be held for the bait market. A facility with 1280 square feet of tank space can probably hold 5000 bait size crayfish with a market value of $2,500. A baitfish crop can also be held in conjunction with the crayfish but this is beyond are capabilities to examine at this time.

It is also difficult to compare this system to single purpose systems such as ebb and flow benches, hydroponic tables, or large aquatic holding tanks. The polyculture system costs more than each one of these type systems viewed separately, however, it can perform the tasks of all three.

The economic analysis assumes that the grower already has a greenhouse operation that is being utilized for one or more activities. The analysis looks at the additional costs of installing the polyculture system and what the potential crop yields might be using salad mix as the example.

TABLE ONE: Production Unit Cost

		Experimental 320 sq ft	Scaled-up 1280 sq ft
Bench Structure			
Speedrail fittings and pipe		$1904.00	$7616.00
Plywood top		$ 404.00	$1616.00
Cement blocks		$ 42.00	$ 168.00
Labor to assemble: 16 man hours @ $8.00/hr		$ 128.00	$ 512.00
	Sub-total	$2478.00	$9912.00
Tank Top			
Fiberglass tanks		$2300.00	$9200.00
tank fittings (drains and risers)		$ 122.00	$ 488.00
	Sub-total	$2422.00	$9688.00
Mechanical Systems			
Air compressor		$ 449.00	$ 449.00
Sump tanks 4 @ $119		$ 476.00	$ 952.00
Pumps, mag drive 1200 gph (2)		$ 185.00	$ 370.00
Ozone UV unit; 40 watts		$ 287.00	$
Venturi injectors (2)		$ 84.00	$
Controller and electric valves		$ 181.00	$ 362.00
Pipe fittings		$ 692.00	$1000.00
	Sub-total	$2354.00	$3133.00
Bio-Cord			
Bio-Cord 200 ft @ $1.30/ft		$ 260.00	$ 520.00
PVC pipe and fittings		$ 86.00	$ 172.00
	Sub-total	$ 346.00	$ 692.00
Monitoring System			
Octopus 3000 controller; probes; cables		$ 530.00	$ 700.00
Hanna Agritest pocket PH/EC pen		$ 83.00	$ 83.00
Remote transmitter boxes		$ 24.00	$
	Sub-total	$ 637.00	$ 783.00
Total cost: 1280 sq ft production unit			$24208.00

TABLE TWO: Economic Feasibility of salad mix production

A. Production unit fixed cost:		$24208
B. Income		
<u>September - March</u>		
Experimental unit (160 sq ft):	400 pounds @$4	$ 1600
Fully planted unit (1280 sq ft):	3200 pounds @$4	$12800
<u>March - June</u>		
Fully planted unit (1280 sq ft):	3200 pounds @$4	$12800
	Sub-total salad production income	$25600
<u>June - September</u>		
Bait sales		$ 2500
	Total income:	$28100
C. Production expenses of fully planted unit		
Plants (6000 starts @ $.10)		$ 600
Oil (500 gal @ $1.00)		$ 500
Fertilizer (2 bags ea; hydrosol, cal-lite, magnitrate)		$ 154
Labor		
crop maintenance (400 h @ $7)		$ 2800
harvest and process 3200 lbs		$ 3200
Electricity & water		$ 200
Misc (equipment, repairs)		$ 200
	Subtotal variable expenses	$ 7654
D. Annual capital recovery		
10 year greenhouse structure ($14000 @ 10%)		$ 2400
5 year plastic ($500 @ 10%)		$ 150
Polyculture system ($24200 @ 10%) 10 years		$ 4420
	Total fixed and variable costs	$ 14624
E. Net returns (Income minus total costs)		
		$ 13476

Project Summary

The demand for farm raised aquatic products is growing at an astounding rate worldwide and in Massachusetts. This project demonstrated a mechanism for small farms and nurseries in Massachusetts to get into this growing market using technology that they are familiar with and that can also be utilized as a more environmentally sound/cost effective means to produce their traditional plant crops. The system can be designed around off-the-shelf equipment readily available to growers through their normal greenhouse suppliers or aquaculture suppliers. Interestingly, aquaculture supply houses are now carrying full lines of hydroponic growing supplies. The distinction between aquaculture, hydroponics, and ebb and flow systems is rapidly disappearing. A new term has been coined, aquaponics, which refers to the integration of these technologies.

Virtually every farm and nursery with a greenhouse can try a basic polyculture system on a limited scale for as low as $2000 in equipment. Each grower will have to identify the proper production mix for their individual operation and potential markets. We were not able to shed much light on the economic potential of the alternative aquatic crops by the conclusion of this project. Demonstrating the environmental benefits and the multiple production strategy hopefully provided the added incentive for commercial application.

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APPENDICES

I. Photographs of polyculture system

II. Environmental and crayfish data from project

III. Hydroponic growing systems

IV. Ebb and flow irrigation systems

V. Baitfish species

VI. Bio-Cord fact sheets

VII. Equipment literature
    - Speedrail fittings
    - U/V Sterilizer
    - Aquadyne controller