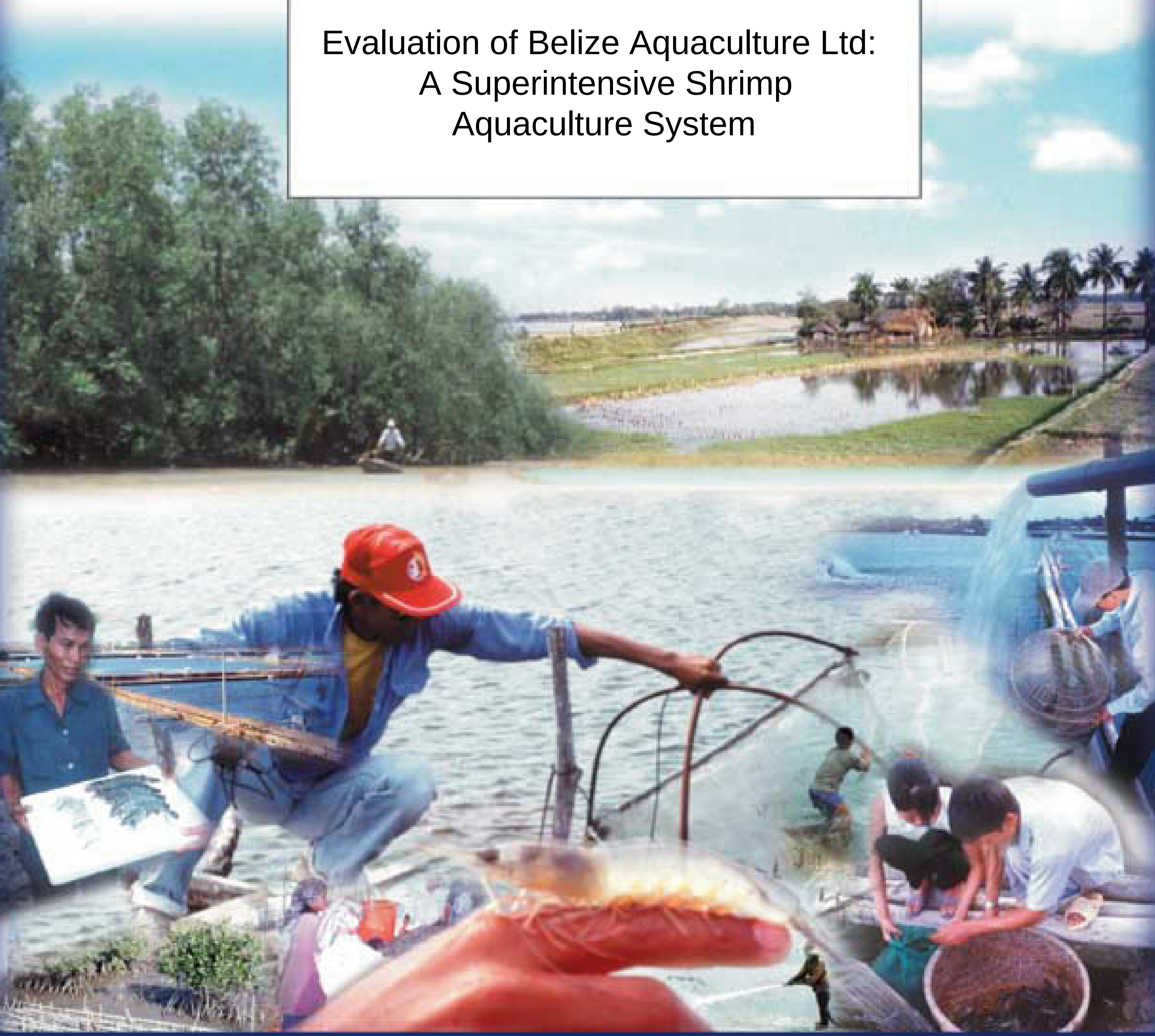
Shrimp Farming and the Environment

Evaluation of Belize Aquaculture Ltd: A Superintensive Shrimp Aquaculture System



A Consortium Program of:

EVALUATION OF BELIZE AQUACULTURE LTD: A SUPERINTENSIVE SHRIMP AQUACULTURE SYSTEM

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Preparation of this document

The research reported in this paper was prepared under the World Bank/NACA/WWF/FAO Consortium Program on Shrimp Farming and the Environment. Due to the strong interest globally in shrimp farming and issues that have arisen from its development, the consortium program was initiated to analyze and share experiences on the better management of shrimp aquaculture in coastal areas. It is based on the recommendations of the FAO Bangkok Technical Consultation on Policies for Sustainable Shrimp Culture[1], a World Bank review on Shrimp Farming and the Environment[2], and an April 1999 meeting on shrimp management practices hosted by NACA and WWF in Bangkok, Thailand. The objectives of the consortium program are: (a) Generate a better understanding of key issues involved in sustainable shrimp aquaculture; (b) Encourage a debate and discussion around these issues that leads to consensus among stakeholders regarding key issues; (c) Identify better management strategies for sustainable shrimp aquaculture; (d) Evaluate the cost for adoption of such strategies as well as other potential barriers to their adoption; (e) Create a framework to review and evaluate successes and failures in sustainable shrimp aquaculture which can inform policy debate on management strategies for sustainable shrimp aquaculture; and (f) Identify future development activities and assistance required for the implementation of better management strategies that would support the development of a more sustainable shrimp culture industry. This paper represents one of the case studies from the Consortium Program.

The program was initiated in August 1999 and comprises complementary case studies on different aspects of shrimp aquaculture. The case studies provide wide geographical coverage of major shrimp producing countries in Asia and Latin America, as well as Africa, and studies and reviews of a global nature. The subject matter is broad, from farm level management practice, poverty issues, integration of shrimp aquaculture into coastal area management, shrimp health management and policy and legal issues. The case studies together provide an unique and important insight into the global status of shrimp aquaculture and management practices. The reports from the Consortium Program are available as web versions (http://www.enaca.org/shrimp) or in a limited number of hard copies.

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Reference:
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[1] FAO. 1998. Report of the Bangkok FAO Technical Consultation on Policies for Sustainable Shrimp Culture. Bangkok, Thailand, 8-11 December 1997. FAO Fisheries Report No. 572. Rome. 31p.

[2] World Bank. 1998. Report on Shrimp Farming and the Environment – Can Shrimp Farming be Undertaken Sustainability? A Discussion Paper designed to assist in the development of Sustainable Shrimp Aquaculture. World Bank. Draft.

Abstract

Belize Aquaculture, Ltd., has developed a superintensive shrimp aquaculture system operating in lined ponds with heavy mechanical aeration and water recirculation (Mcintosh 1999; Mcintosh et al. 1999). The pilot study of the operation has been in progress for two years, and several different trials have been conducted in ponds of 0.065 to 1.6 ha in size. Shrimp production has ranged from less than 8,000 kg/ha to more than 20,000 kg/ha per crop.

Such high production per unit area without water exchange presents several advantages over conventional shrimp aquaculture. These include greater potential for mechanization, reduced use of land and water, fewer logistical problems in pond operations, and less effluent. If this system works as efficiently as the early data suggest, and if it is suitable for general adoption by shrimp farmers around the world, it could provide a more environmentally responsible method of shrimp production.

Because the Belize Aquaculture, Ltd., production system appears to address a number of the environmental impacts of traditional shrimp aquaculture systems, a case study of this unique system was conducted. The case study was also intended to evaluate the potential of the system for replication throughout the world. The specific objectives of the case study were to:

1. Describe the production system,
2. Present a summary of its performance,
3. Discuss the unique aspects of the system,
4. Compare the system with conventional shrimp production systems,
5. Identify potential areas of concern with the current Belize Aquaculture system,
6. Discuss the implications of expanding the current system in Belize, and
7. Assess the socioeconomic factors and effects of shrimp culture by this method.

Content

Abbreviations and Accronyms

$	American dollars
B$	Belize dollar (1 US$ = 1.97 B$ at Jan. 2002 rates)
$CaCO_3$	Calcium Carbonate
CFU	Colony Forming Units
cm	Centimeter
ESOP	Employee Stock Option Program
FAO	Food and Agriculture Organization of the United Nations
g	Gram
ha	Hectare
hp	Horse power
kva	Kilovoltamps
kW	Kilowatt
kWh	Kilowatthours
l	Liter
m	Meter
m^2	Square meter
m^3	Cubicmeter
mg	Milligram
ml	Milliliter
NACA	Network of Aquaculture Centres in Asia-Pacific
PL	Post Larvae
ppt	Parts per thousand
SPF	Specific Pathogen Free
wk	Week
WWF	World Wildlife Fund

The Production System

The site

The pilot production facility is located on Blair Atholl Estate in the Stann Creek District of Belize (Figure 1), at about 16.5°N latitude. Mean monthly air temperatures range from 23°C in winter to 27°C in summer (annual mean = 25.3°C). Annual rainfall averages 2,203 mm, and the dry season is from February through April. The facility is situated near the west shore of Placencia Lagoon.

Figure 1: Map of Belize (Source: The University of Texas in Austin 2001 at: http://www.lib.utexas.edu/maps)

The land upon which the facility was constructed consists of highly acidic sand and clay soils that are low in nutrients and high in aluminum (King et al. 1989). Ecologically, the location is considered a pine savannah, but the salt content of the soils makes them marginal for agricultural or pasture use. The elevation of the pilot project is 6 meters above mean sea level. Location of the facility well above sea level should provide considerable protection from the hurricanes that occasionally hit Belize. Because the site is more than a kilometer from the ocean, there is little chance of disease contamination from the wild. For instance, no crabs have ever been found in the ponds during harvest.

The Facility

The pilot facility consists of the following major components:

- Production ponds 650m^2 (16); 3,700 m^2 (8); 1 ha (1) and 1.6 ha (1); this gives a total of 66,000 m^2
- Settling ponds 7,000 m^2 (2); 14,000 m^2 total (21.2 percent of production pond area.
- Seawater reservoir, 5,000 m^2.
- Maturation/hatchery/office complex.
- Warehouses complex.
- Electric generator, 230 kva (4).

- Housing complex for workers and management.
- Acclimation station.
- Pumping station with brackish water intake.
- Pumping station with seawater intake.

Seawater is taken from 150 m offshore of the Placencia Peninsula and carried by pipeline across the Placencia Lagoon to the farm's seawater reservoir that serves as the water source for both the hatchery and ponds. The seawater may be pumped directly from the reservoir to the ponds or it can be gravity-fed to the settling basins for aging and conditioning. During the dry season, freshwater can be pumped from a creek into the two settling basins to reduce excessive levels of salinity but this has never been done because the operation has not seen any impact on production correlated with increased salinity. Water from the sea and the creek is passed through a 160-micron filter bag to remove fish, crabs, and other unwanted organisms. It was found that 250-micron filter bags allowed barnacle larvae into the ponds that became a nuisance and had to be scraped down after harvest. Water from settling basins must be pumped back to ponds.

Ponds are square, with depths of 1.4 m at the edges and 2.3 m at the deepest point in the middle. Because the ponds at Belize Aquaculture are deeper than conventional ones, 1 ha of Belize Aquaculture ponds has the volume equivalent to about 1.5 ha of traditional ponds. All ponds are lined with HDPE plastic that extends to the top of the embankment. Thus the sides of ponds can be steeper than in conventional shrimp ponds because there is less erosion. This feature in turn makes it more difficult for wading birds to eat the shrimp. The tops of pond embankments have been covered with erosion matting material and planted with St. Augustine grass. The bottom of each pond slopes towards the drain in the middle. Each pond has a standpipe for water level control that can be removed for draining at harvest. Aeration has been used at 28 horsepower (hp)/ha in the 3,700-m^2 and 1.6-ha ponds and at 60 hp/ha in the 650-m^2 ponds. Aeration has been accomplished by using both electric paddlewheel aerators and propeller-aspirator-pump aerators.

Management

All shrimp used in the grow-out operations originated from Specific Pathogen Free (SPF) broodstock from the company High Health Aquaculture. Four lines have been used: *Peneaus vannamei*, Mexican strain; two Taura Syndrome virus-resistant strains (TR 2 and TR 5), and *P. stylirostris*, Ecuadorean strain. A broodstock domestication program has been initiated at Belize Aquaculture to develop shrimp stock that are best suited for the unique culture conditions of the operation. Post larvae are acclimated for 48 hours and then stocked into ponds in the early morning.

When ponds are refilled from the settling basin, no preparation is necessary other than the application of dolomitic limestone to restore water alkalinity. When ponds are filled with seawater, a 10-day preparation regime is used before stocking. Ponds are fertilized with ammonium nitrate, ammonium phosphate, and a micronutrient mix; dolomite is also added. Denitrification produces acidity and causes total alkalinity to decline during production. Consequently, total alkalinity is monitored during the crop, and limestone is applied if alkalinity falls below 60 mg/l. Organic material (a pelleted mix of soybean meal, ground wheat, and corn) is applied at 10 kg/ha per day. Organic matter applications are intended to stimulate microbial populations.

Stocking densities for *P. vannamei* ranged from 80 to 160 PL(post larvae)/m^2, while *P. stylirostris* has been stocked at 55–65/m^2. Robin Mcintosh (1999, personal communication) estimates stocking densities of 115–125 PL/m^2 in the summer when animals grow faster. By contrast, in the winter, when growth slows because of water temperature, stocking rates are 140–170 PL/m^2. Winter stocking is more dense because shrimp grow slower. Management wants to produce the same weight of shrimp per hectare in the cycle, even though the winter crop will be smaller and have lower value. Culture cycle length has averaged 139 days for *P. vannamei* and 158 days for *P. stylirostris*. At this point, *P. stylirostris* is not being produced commercially.

After stocking, two types of pelleted feed are used. The first feed used after stocking (comprising one-third of all feed used) is 18% protein, and contains no fishmeal. The second feed used contains 14% fishmeal and 30% total crude protein. Feed is offered twice per day at the beginning of a crop, increasing to five times per day closer to harvest, when weight gain is increasing.

Water exchange has not been intentionally applied, but new water must be added to replace evaporation, and rainfall may cause overflow. Management estimates 1.6 pond fillings per crop. Sludge is removed from ponds by running a hose over areas where sludge has accumulated and pumping it into the drainage canals that run to the settling basin.

Aeration is used 24 hours a day throughout the crop; only 50% of aerators are operated during the day, while all aerators are operated at night. If pond water temperatures become too high, all aerators may be operated in daylight hours to help cool the water.

Shrimp harvests are undertaken by steadily draining the water level to approximately half the total volume. The aerators are kept running as long as water levels allow. In the larger ponds, a net is pulled through the pond to force the shrimp toward the drain, to minimize the duration of oxygen deprivation. A modified fish pump is used at the exit gate from the pond, in order to separate the water from the shrimp. The shrimp are pumped up into an overhead bin, from which they are passed via a chute into large insulated boxes on trailers. The shrimp are immediately iced down to prevent spoilage. Stranded shrimp are collected by hand from the floor of the pond and added to the harvest. The pond water passing directly through the harvest pump goes directly to the drainage canal, where it passes into a settling pond.

Once ponds are drained, any remaining solids are washed from the pond liners with a high-pressure stream of water. The solids on the pond bottom in this system are more gelatinous than those found in traditional ponds, as the constant aeration and movement of the water continuously break them down. Barnacles are also scraped by hand from the plastic liners.

Goals of Belize Aquaculture

According to Mcintosh et al. (1999), the goals of Belize Aquaculture are the following:

1. Produce 2.5 crops per year of 11,200 kg/ha per crop using a culture system based on zero water exchange, water reuse after harvest, lined ponds, and high-health shrimp.
2. Determine the most appropriate pond size for commercial application and the engineering required to operate such a pond.
3. Select the best species and strains of shrimp for this culture system.
4. Develop operational skills and experience needed to successfully operate the system.

Results

Yields

During the initial 23 months of the pilot project, Belize Aquaculture ponds produced 63 harvests. The average yield of all harvests was 11,231 kg/ha per crop. Some 55% of all harvests produced yields greater than 13,600 kg/ha. Harvests lower than 13,600 kg/ha generally occurred in ponds stocked with the Taura syndrome virus-resistant strains of *P. vannamei* or *P. stylirostris*. In order to achieve 13,600 kg/ha or more, Mcintosh (1999) reported that it was necessary to stock the Mexican strain of *P. vannamei* at 120/m^2 or more and use at least 30 hp/ha of aeration.

The highest yield of 27,200 kg/ha was achieved in 650-m^2 ponds aerated at 60 hp/ha and containing 1,350 m^2 of vertical surfaces created with AquaMats^{TM}. AquaMats^{TM} appear to increase production by improving performance in several ways. First, they provide surface areas on which food can grow, reducing the overall feed-conversion ratio from 2:1 to 1.4:1. This roughly 30% reductions in feed costs per animal produced reduce the overall cost of producing shrimp by $0.27/kg. The lower feed-conversion also decreases the amount of wild fish needed to manufacture the shrimp feed. The use of AquaMats^{TM} also increases the survival rates, both in hatcheries and in the ponds. Shrimp are territorial; the mats appear to give shrimp, particularly younger ones, more surface area to stake out.

The results in the 1.6-ha pond have been impressive and suggest that production levels similar to those obtained in smaller ponds can be achieved in larger ponds of 1 ha or greater in area. Mcintosh (1999) reported production of 13,400 kg/ha/crop in the 1.6-ha pond. During our visit to Belize Aquaculture, we watched the harvest of the 1.6-ha ponds, when about 50,000 lbs of shrimp were removed, equivalent to about 14,172 kg/ha of live shrimp.

Water Quality

The ponds are fed a combination of the organic mix and shrimp feed from the beginning of the cycle in amounts greater than the shrimp can consume. The high input of organic matter with continual mixing by the aerators results in a lot of organic particles, or floc, suspended in the water. The floc makes the ponds equivalent to activated sludge ponds or bioreactors.

The ponds start with a phytoplankton bloom (green water), but after 8 to 10 weeks the waters become turbid with particles covered by bacteria. The color of the water changes noticeably from green to brown, and finally to black. A sodium silicate by-product of zeolite manufacturing (from Engelhard Corporation, Attapulgus, Georgia) appears to encourage formation of bacterial floc in pond water. Bacterial counts were typically about 100,000 colony-forming units (CFU)/ml initially to 100,000,000 CFU/ml just before harvest.

Salinity of pond water ranged from a low of 16 ppt in December to 39 ppt in June, but this variation in salinity did not appear to influence shrimp growth. Pond water temperatures, measured weekly, averaged between 23°C and 32.5°C. In contrast to salinity levels, temperature was a major factor influencing shrimp growth. Ponds stocked in September and October had lower growth rates (0.6 to 0.7 g/wk) than ponds stocked from April to June, which had an average growth rate of 0.95 g/wk. Nevertheless, yields greater than 11,300 kg/ha were achieved throughout the year.

Heavy mechanical aeration is required to maintain sufficient dissolved oxygen in the ponds. This is particularly true during the night, when there is no photosynthesis to produce oxygen. Full nightly aeration is required to ensure that morning oxygen concentrations do not fall below 4 or 5 mg/l.

Aeration is essential in this aquaculture production system in order to maintain high dissolved oxygen concentrations for the shrimp and to support aerobic decomposition of organic matter and nitrification by bacteria. If aerators are turned off in a pond, the dissolved oxygen levels may fall by 3 to 4 mg/l within an hour. Aeration also produces water currents, which maintain the bacterial floc in suspension. Monitoring oxygen levels is perhaps the single most critical management function.

Because of the high inputs of nitrogen in feed, total ammonia nitrogen concentrations reach 10 mg/l after 3 to 5 weeks. However, nitrification then becomes a major factor and nitrifying bacteria rapidly convert ammonia nitrogen to nitrate. This results in a decline in total ammonia concentrations to 1 or 2 mg/l, and the levels remain at this level until harvest. This is beneficial because ammonia at high concentration (above 4 or 5 mg/l) can be harmful to shrimp. Nitrate concentrations may reach 15 mg/l, but nitrate is not harmful to shrimp at concentrations below 50 mg/l.

Nitrification also releases hydrogen ions that neutralize alkalinity. In some early trials, total alkalinity declined to 15 mg/l as equivalent $CaCO_3$. To counteract the loss of alkalinity, dolomitic limestone is periodically applied to the ponds, with the objective of maintaining alkalinity at 80 mg/l or higher. Through such liming, the pH of the water is maintained at 7.2 to 7.4.

Soluble reactive phosphorus and total phosphorus are very high in pond waters. Typical concentrations are between 7 and 10 mg/l, respectively. Using the nonograph method (method for estimating carbon dioxide concentration from temperature, pH, total alkalinity and total dissolved solids) carbon dioxide concentrations are 10-15 mg/l for all ponds. The titration method appears to overestimate carbon dioxide levels for the same water at from 50 to 100 mg/l. Even if there were too much carbon dioxide, the shrimp are not stressed because the system has high and stable levels of dissolved oxygen.

Feed Conversion and Nitrogen Recovery

The average crude protein content of the feed (organic mix and commercial feed) was 24% in 1999, but had been reduced to 21.5% by 2000. The fishmeal content of the total feed input is 7.8%. The feed conversion ratio has been about 2. A typical nitrogen budget for a culture cycle revealed that 39% of nitrogen applied to ponds in feed and nearly 50% of phosphorus was recovered in the shrimp harvested (Mcintosh 1999, personal communication). This nitrogen recovery rate is much higher than the capture of 15–25% typically produced in conventional aquaculture operations (Boyd and Tucker 1998). The feed's fishmeal content and the feed conversion ratio mean that Belize Aquaculture produces 1 kg of shrimp with less than 1 kg of wild fish (converted to fishmeal)[3]. This is much better than the ratio of 2–4 kg of wild fish per kilogram of shrimp that has been reported for conventional operations (Naylor et al. 1998). Management has observed that the post-larvae survival rate declines with feed containing higher protein levels, particularly fishmeal protein. Nitrogen input also declines relative to total carbon when using lower fishmeal feeds. In fact, management believes the latter has more to do with improving overall survival rates than the reduced use of fishmeal, but the two are not unrelated (Mcintosh 1999, personal communication).

Energy Use

The major consumption of energy is for mechanical aeration. Aerators are operated at 75% capacity. Thus, aeration rates per horsepower mentioned above are for the applied horsepower; e.g., a 10-hp aerator loaded at 75% is 7.5 applied horsepower. Assuming 30 applied horsepower of aeration per hectare and 75% operating time per day (100% at nighttime and 50% in daytime), the average applied horsepower per day is 22.5 hp. Furthermore, motors are not completely efficient. Assuming an efficiency of 90%, the kilowatt use will be (22.5 hp ÷ 0.90) × 0.745 kW/hp × 24 hours/day = 447 kWh/day.

The average production cycle is about 130 days in summer and 135 days in winter. Using 132.5 days for the average production period, aeration will require 59,227.5 kWh/crop. If the average production is 13,600 kg/ha per crop, electricity for aeration will amount to 4.35 kW·hr per kilogram of shrimp. According to Boyd and Tucker (1998), the electricity cost for mechanical aeration of intensive shrimp ponds in Thailand, where the average production rate was 5,000 or 6,000 kg/ha, was about 4.5 kWh per kilogram of shrimp.

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[3] The ratio used to convert wild fish to fishmeal is 5:1 (Tacon 2002) See also Table 3 regarding fishmeal per unit of shrimp.

Pumping costs for the Belize Aquaculture production system are much less than for traditional shrimp aquaculture systems that use water exchange. Also, energy use for vehicles is much less per unit of shrimp production than for large semi-intensive ponds because much shorter travel distances are involved. Taken as a whole, then, it is likely that the intensive Belize Aquaculture production system uses less energy per kilogram of shrimp produced than the semi-intensive systems that are common throughout Latin America.

Belize Aquaculture's energy costs are high at this time, more than $0.15/kWh. With improved efficiency in the on-site generation capacity, management believes that the cost can probably be reduced to approximately $0.09/kWh.

Water Use

The system is very water-efficient. There is no water exchange, and most water is recycled. Mcintosh et al. (1999) estimate that about 2 m^3 of water are required per kilogram of shrimp produced, and the authors' data collection supports this figure. However, since most of the water is reused, it appears that with current levels of evaporation and water use, the actual figure is about 1 m^3 of water per kilogram of shrimp produced. For example, we observed a harvest of 22,675 kg of shrimp from the 1.6-ha pond. The pond is 2 m deep and had been filled 1.6 times. Thus, a total of 51,200 m^3 of water had been used, which works out to 2.26 m^3 of water per kilogram of shrimp.

Settling Basin

Water released from ponds during rains, sludge removal, and harvest enters the settling basin. Shrimp pond solids settle quickly in the basins. Typically, the water discharged during harvest has a Secchi disk value of 21–30 cm. An example of settling basin performance is provided in Table 1. The water is in the settling basin for three to seven days before being returned to production ponds.

Table 1. Changes in water quality parameters during first week of aging in settling basin.

Parameter	Day 1	Day 7	Change
Dissolved oxygen, AM (ppm)	0.3	0.8	+0.5
Dissolved oxygen, PM (ppm)	0.5	3.5	+3.0
Secchi disk visibility (cm)	23	75	+52
Total alkalinity	35	95	+60
Total ammonia-N (ppm), NH_3/NH_4	1.6	1.5	-0.1
Nitrate-nitrogen (ppm), NO_3	4.5	0.6	-3.9
Nitrite-nitrogen (ppm), NO_2	9.5	0.4	-9.1
Total nitrogen (ppm)	22	6.0	-16.0
Total phosphorus-P	7.0	1.35	-5.65
PH	8.2	8.6	+0.4

Source: Mcintosh, Drennan, and Bowen 1999.

The chemical composition of the sludge from the settling pond is provided in Table 2. Mcintosh et al. (1999) estimated that 720 g (dry weight) of sludge resulted from each kilogram of shrimp produced.

Table 2. Chemical composition of sludge from settling basin (mean of 3 samples).

Parameters	Mean Value
Total solids (gms dry wt/lb shrimp harvested)	720
% moisture after 3-day sun dry	52
PH	7.5
Sediment redox (oxidation-reduction potential)	-450
Total nitrogen (N g/kg dry wt.)	10.5
Phosphorus	4.5
Calcium	9.5
Iron	3.5
Copper (mg/kg dry wt)	8.5
Organic matter (% dry wt)	65
Ash (% dry wt)	35

Source: Mcintosh, Drennan and Bowen 1999.

The high levels of organic matter, nitrogen, and phosphorus of the sludge make it a suitable organic amendment for agricultural soils once the salt has been sufficiently reduced.

Labor Systems

Belize Aquaculture, Ltd., employs fewer laborers per kilo of production than conventional shrimp aquaculture operations in Latin America, but more laborers per hectare of ponds. This apparent contradiction results from the higher productivity of the system. Workers live on site and the company pays for housing and electricity. Workers pay their other costs. Workers are on duty for 24 days and off for 6. All employees are employed "at will," but there is some redress in Belize for certain types of dismissal. The most common causes for dismissal are theft and absenteeism. Standard severance pay is one month of salary for each year worked.

The starting base salary is B$1,000–1,200, which compares favorably with B$700 for other rural workers. Supervisors receive B$1,500–1,600 per month. Daily wages for occasional labor are B$30 versus the usual B$20 for agricultural day labor in Belize. Every laborer has a three-month probationary period.

During the pilot phase, the company has 26 employees, with 13 acres of production. Twelve of the employees work in the hatchery, six are involved in maintenance of plant facilities, two are domestic staff, five work on pond management, and one is the manager. None of the workers or management staff receive bonuses or incentives based on production.

According to Mcintosh, the Belize Aquaculture system requires less-skilled laborers than do conventional systems (Mcintosh 1999, personal communication). Many more people, moreover, are needed in conventional systems to monitor and maintain water quality. In his words, "It is a lot harder to manage a 20–40 hectare aquarium than it is to manage a sewage treatment plant." He also pointed out that in this system, "if you can manage the oxygen with aerators, everything else takes care of itself."

Unique Aspects of the Production System

The production system developed by Belize Aquaculture is unique. To the authors' knowledge, no similar aquaculture production system has been tested for any species anywhere in the world. Many of the basic principles and individual practices in the Belize Aquaculture system have been used in shrimp (and other) aquaculture, including zero water exchange, lined ponds, mechanical aeration, water recirculation, sludge removal, mechanization, pure lines of disease-resistant/high-health shrimp, and low-protein feed. However, Belize Aquaculture is the first commercial enterprise to incorporate numerous innovations into an unique culture system that permits superintensive shrimp production in lined ponds with heavy aeration and water reuse.

Most aspects of the system appear quite advantageous for shrimp culture in general. Zero water exchange and water reuse reduce pumping costs, conserve nutrients in ponds, reduce effluent volume, prevent entrance of biological contaminants and pathogens from outside of ponds, and minimize escape of the culture species into the environment.

However, even in a system with mechanical aeration and sludge removal, water quality deteriorates without water exchange. The heavy aeration necessary to allow intensive shrimp production in earthen ponds badly erodes the embankments and bottoms of ponds, and the suspended soil particles and organic matter settle in areas of the ponds where water currents are slowest (usually the center). Decomposition of organic matter in these sediment mounds results in highly anaerobic conditions and release of potentially toxic microbial metabolites into the pond water (Boyd 1992). Sludge pumps are not efficient in removing organic matter from such ponds because the organic matter is mixed with a large volume of soil with heavy mineral content. In Asia, farmers often remove the sediment from pond bottoms between crops with excavating equipment or by applying high-pressure water jets. Disposal of the sediment on land or discharge of sediment into canals can cause serious negative environmental impacts (Boyd et al. 1994).

The high feeding rates necessary to produce large amounts of shrimp cause water quality impairment in culture ponds (Dierberg and Kiattisimbul 1996). Such water has a high biological oxygen demand and high concentrations of total ammonia nitrogen, total suspended solids, and phytoplankton. Release of such pond waters into the environment represents a large pollution load. Assimilation of wastes from feeding occurs in ponds, but much of the decomposition of organic matter is the result of anaerobic processes occurring in the bottom sediment (Boyd and Tucker 1998). Thus, even with a high rate of water exchange and heavy mechanical aeration, water quality will deteriorate in earthen shrimp ponds as feeding rates increase. Consequently, production will seldom exceed 5,000 or 6,000 kg/ha in conventional shrimp culture ponds.

Belize Aquaculture achieves high production rates by combining lined ponds with low-protein feed, heavy mechanical aeration, and sludge removal—thereby avoiding the water quality problems of conventional systems. In this system, a tremendous production of phytoplankton and accumulation of ammonia nitrogen occurs initially, as in other types of shrimp culture. However, after a few weeks the phytoplankton diminishes in abundance and is replaced by a floc which is an inorganic matrix of calcium and silicates that are colonized by bacteria. According to the work of Rod McNeil on the floc in the ponds, there is no non-living organic matter associated with the flocs. The protein level of the flocs is about 45% and the ash level is about 30% of suspended organic particles. Because of the high rate of aeration, water currents are strong in the ponds, and these water currents maintain the floc in suspension. The liner prevents the suspension of mineral and soil particles in the water, so the water does not become turbid (“muddy”) with clay and fine silt particles from the sides or bottom.

The paddle-wheel aerators are positioned to cause a circular flow, and propeller aspirator-pump aerators are positioned to resuspend particles that settle in the center of the pond where water currents are weakest. By experimenting with the placement of the aerators, management was able to reduce the dead zone in the center of the ponds from an estimated 35-40% to just 15% of the bottom area (Mcintosh 1999, personal communication). Nevertheless, some sedimentation of organic matter occurs near the center of the ponds. At harvest, this sediment is pumped from the ponds and conveyed by water to the settling basins.

The success of the system as a bioreactor results from the following factors:

1. Low-protein feed creates a high abundance of organic particles for bacterial growth and floc formation.
2. Turbidity caused by the floc eliminates light and prevents the growth of phytoplankton after the initial weeks of culture.
3. The bacterial floc is largely suspended by the water currents produced by aeration. The bacterial, floc-based culture provides more consistent water quality than does a phytoplankton-based culture. The bacterial floc also provides another food source for the shrimp that supplements the input of pelleted feed.
4. Heavy mechanical aeration maintains high concentrations of dissolved oxygen in the pond water. (Such aeration is possible because erosion of the mineral-rich soil on the bottom is prevented by the plastic liner.)
5. High concentrations of dissolved oxygen promote aerobic decomposition of organic matter by bacteria, allow efficient and rapid conversion of ammonia nitrogen to nitrate through bacteria nitrification, and prevent low early-morning dissolved oxygen concentrations typical of phytoplankton-based culture methods; such low concentrations stress the shrimp.
6. All sludge removed is organic, because the plastic liner prevents bottom-soil erosion. Sludge is removed to prevent the accumulation of sludge in the centers of ponds; such accumulation would result in zones of anaerobic decomposition common in traditional aquaculture ponds with earthen bottoms.

There are many other desirable features of the Belize Aquaculture system. Some of the key ones are listed below.

1. A high degree of mechanization (e.g., feeding by mechanical feeders and harvesting with pumps) is possible because of the intensive production methods—reducing labor costs per kilogram of shrimp produced.
2. Feed has low protein and fishmeal content.
3. Pure lines of high-health shrimp are used.
4. The system uses little space or water, which reduces the costs of initial investment for land.
5. Energy costs per kilogram of shrimp produced are lower than in conventional aquaculture operations.
6. The use of pond liners permits aquaculture in areas with organic, sandy, acidic, or other types of problematic soils.
7. Because of water reuse, it is not necessary to discharge effluents into the coastal waters that serve as a water source for shrimp farms throughout the area. Consequently, the system is not self-polluting, unlike many other types of shrimp culture systems.

Comparison with Conventional Systems

The unique aspects of the Belize Aquaculture shrimp production system have already been discussed above. Additional insights are revealed by a brief comparison between it and the traditional semi-intensive shrimp culture system used throughout Latin America. In this comparison, it is assumed that the Belize Aquaculture system produces 2.5 crops of 11,200 kg/ha per year and that the traditional systems produce 2 crops of 1,000 kg/ha per year. The results of the comparison are summarized in Table 3.

Table 3. Comparison of various parameters between Belize Aquaculture and traditional production systems

Variable	**Belize Aquaculture production system**	**Traditional semi-intensive system**
Siting	6 m above high tide	1–2 m above high tide
Soil limitations	Stable soil (any texture and chemical composition)	Avoid acidic, sandy, or organic soil
Land use (total)	≈2,000 m^2 per ton of production capacity	≈ 15,000 m^2 per ton of production capacity
Water requirements	1 m^3/kg shrimp	40–80 m^3/kg shrimp
Stock characteristics	High-health shrimp, farm-raised broodstock, hatchery post- larvaes	Variable—often, wild (caught) broodstock or post-larvaes
Electrical requirements	4–5 kW-hr/kg shrimp	Minimal, but lots of diesel fuel needed
Vehicle use (trucks, tractors, etc.)	Intensive, but over small area	Equally intensive, but over much larger area
Stocking rate	115–130 PL/m^2, depending on season	8–10 PL/m^2
Feed use	20–24 tons/ha per crop	2–3 tons/ha per crop
Feeding rate	Maximum of 300–400 kg/ha per day	Maximum of 30–40 kg/ha per day
Feed protein converted to shrimp protein	40%	15–25%
Feed protein per unit of shrimp	0.4–0.5 kg/kg shrimp	0.6–0.9 kg/kg shrimp
Fish meal per unit of shrimp	0.14–0.17 kg/kg shrimp	0.4–0.6 kg/kg shrimp
Fertilizer use	0–100 kg/ha per crop	500–600 kg/ha per crop
Lime use	2–3 tons/crop	1–2 tons/crop
Effluent volume	None	40–80 m^3/kg shrimp or 400,000–800,000 m^3/ha per crop
Seepage to groundwater	None, if canals and settlement ponds are also lined	1,000–2,000 m^3/ha per year
Erosion from earth works	Very little (probably about 1 ton/ha per year)	20–100 tons/ha per year
Solid wastes	≈ 0.75 kg/kg shrimp	Very little

The environmental benefits of the Belize Aquaculture shrimp culture system are considerable compared to traditional semi-intensive shrimp aquaculture production systems. Because of water reuse the system is 20 to 40 times more efficient in total water requirements. Moreover, the Belize system is over five times more efficient in land use than semi-intensive systems. These two factors alone could substantially reduce the environmental impacts of shrimp aquaculture if this innovative system were adopted more widely. This system also provides more efficient use of feed protein and fishmeal than conventional systems. No effluent is produced, and no seepage results, because water is reused and pond bottoms are lined, greatly reducing the potential for pollution of coastal waters and salinization of groundwater.

In the Belize Aquaculture system, grass could be established on embankments to reduce erosion. Because the ponds are well above the tidal zone, the soils are less saline. In conventional shrimp aquaculture systems, embankments are difficult or impossible to plant with short grasses due to the high salinity of the soils. Erosion of embankments is a major source of suspended solids in the effluent from conventional shrimp farms.

In addition, the Belize Aquaculture system may be constructed on any type of stable soil, because the liner prevents seepage and water contact with the soil. Soil limitations (sandy, acidic, or organic soils) can be major problems in conventional shrimp ponds. Compatibility with a wide range of soils and the low water pumping requirements allow the system to be sited on land outside of the immediate tidal zone. This advantage prevents many of the negative impacts of traditional shrimp farming that result from locating shrimp farms in coastal wetlands. Avoiding coastal wetland sites also reduces the potential for flood damage to shrimp farms posed by hurricanes. For example, Hurricane Mitch caused severe damage to coastal shrimp farms in Honduras, Nicaragua, and El Salvador in 1998.

Concerns About the Current System

There are, however, a few concerns about the Belize Aquaculture system that must be pointed out. The initial investment for the complete system, including all the associated infrastructure, is quite high. In the start-up phase, management estimated that the total cost of expanding the current operation to 300 acres would be about $30 million (or about $250,000/ha). They believe, however, that that figure could be reduced to about $80,000/ha for the construction of ponds, electrification, aeration, and canals. Economies of scale with volume purchases and greater efficiency can reduce the cost considerably as does not building the hatchery, processing plant, or power generation facility.

Several components of the large initial investment could be eliminated or reduced. For example, total investment costs could be reduced by one-third if energy supplies from utilities could be guaranteed. Energy generation currently accounts for about one-third of all up-front capital investments. Another 10–15% of initial investment funds were used to build a processing plant. While this is a way to add value to production at Belize, not all operations would need a processing plant. The hatchery, too, represents considerable investment cost. If post-larvae were readily available in the area, each farm would not need to produce its own. In short, smaller producers might be able to reduce the costs of constructing shrimp operations, but this would depend on the availability of energy, local hatcheries, and processing plants. Even so, it is doubtful that smaller producers could reduce the cost of constructing a one-hectare operation to much less than even $80,000. And this low cost would depend upon a larger entity's purchasing some of the materials in bulk and distributing them.

Operating costs within the system are low per unit of production, but high per hectare since so much more shrimp is being produced. Reducing capital investments would most likely increase operating costs. For example, the unit cost of electricity produced in one's own facility, if it is efficient, could be lower (and energy supply more reliable) than purchasing it off the grid. Likewise, it may be far cheaper and less complex and risky to purchase post-larvae from reputable hatcheries than it is to set up a hatchery. However, for Belize Aquaculture, the costs of producing post-larvae in their own hatchery are less than a third of the current price for post-larvae in Belize. The hatchery is therefore not only a significant income center, but it also helps the company ensure that shrimp diseases will be kept out of Belize. Belize has not yet been hit by White Spot Syndrome Virus disease, which has affected most Pacific Coast producers in Latin America. While there is less stress in the company's ponds than in semi-intensive operations in Latin America, it is still not clear how disease would affect the system.

Labor poses potential issues. Belize Aquaculture claims that they want to be able to use workers with only a high school diploma. However, it is clear that the company's success currently depends on the skills and experience of a highly trained manager and an owner who has a master's degree in engineering. While it is possible that enough will be learned in this process to develop a cookie-cutter approach to this type of operation or even the development of turn-key operations, it is highly unlikely. New situations and problems will always arise. Having people on hand who can anticipate and prevent problems or, if they occur, limit the damage, will be very important for an operation as complex as this one. Highly skilled managers and workers who can think on their feet will ensure the system's viability.

The settling basin capacity may raise another area of concern. In the current pilot study, the capacity is not adequate. The effluent from harvesting the large pond could not be handled in the current system. When first designed, the settling basin system was 21.2% of the surface area of the production ponds and 23% or so of their volume. Doubling the volume of the settling ponds relative to grow-out ponds may be required to obviate discharging effluents in response to alterations in pond harvest schedules that could occur for unforeseen reasons or emergency situations. Doubling the volume could be accomplished either by increasing the settling ponds' surface area or depth; a combination of both might be the best approach. However, another issue is that the settlement ponds should be lined. Lining would reduce the scouring of the settlement ponds themselves, which adds to the solids in the system. Lining would also facilitate the collection of the solids. Finally, the liners would prevent seepage from the ponds, which could affect freshwater aquifers. Seepage could pose problems for an operation established inland from the tidal zones.

All solid sludge must be disposed of properly, in an environmentally friendly manner. Solid sludge should not be disposed of in freshwater areas. If it is disposed of on conventional agricultural land, the sludge will have to be leached of salts first, in order to prevent salinity damage. Some saltwater-tolerant species could perhaps benefit from the organic matter or even the application of liquid sludge, for example cashew trees and some oil seed crops from Africa. Israel has also developed several commercially viable salt-tolerant species that might be appropriate cash crops for Belize.

The Belize Aquaculture production system is best suited for the production of shrimp species such as *P. vannamei* that tend to be more omnivorous than carnivorous. These species can utilize lower-protein feed as well as benefit from eating the bacterial floc. More carnivorous species such as *P. monodon* require higher-protein feed, and they may not be able to utilize the bacterial floc as effectively as *P. vannamei* or other more omnivorous species (including *P. indicus)*. Nevertheless, because of stable water quality in the system, it may still be possible to stock it with *P. monodon* and other more carnivorous shrimp species, if management can accept lower production levels. It is not clear, however, whether production levels lower than those achieved at Belize Aquaculture are economically feasible, due to the high initial investment. The system may also be usable for fish aquaculture production.

Issues Related to the Expansion of the Current Belize Aquaculture System

The Belize Aquaculture shrimp aquaculture production system has been impressive to date. It has addressed many of the issues that raise the most concern about the long-term impact and sustainability of the shrimp aquaculture industry. There are a few issues, however, that should be addressed if the operation is to expand. The next stage currently proposed is to expand to 120 ha, and eventual plans call for doubling to 240 ha for Belize Aquaculture and 960 ha of ponds created by a consortium of producers.

The main issues that should be addressed in the expansion phase of this operation are discussed below.

1. The effluent system should be closed. While permitting might include a proportion of effluent that could be released into the environment on an emergency basis, the goal of the company should be to eliminate all effluents. To achieve the full potential of this operation, this goal should be achieved as soon as possible.
2. Any released effluents should go directly into the ocean rather than semiclosed lagoon systems, which have low water evacuation rates. Any released effluents should come from the beginning of the pond draining, not from the end, when the effluents contain most of the sediment load. These sediments must be settled before effluent is released to reduce their impact.
3. The company should decide how to manage sediments in the ponds. It should either manage them steadily throughout the production process, or leave them in place and take them only after the harvest. Stirring up the sediments prior to harvest can create toxic zones that kill shrimp.
4. The ratio of settlement-to-pond volume is not sufficient at this time. The volume of settlement ponds should represent at least 15–20% of pond water volume. Capacity should exceed anticipated need, because problems will arise that cause initial calculation of need to be exceeded (e.g., disease, cold weather, and storms). On the new farm, for example, settlement ponds should hold 120% of the anticipated pond water volume.

5. In the old system, settlement ponds were not lined. They are lined in the new farm. This will prevent seepage into the environment and will facilitate the collection of the sludge. Lining the canals is less important so long as they are not used to hold water for days on end like the settlement ponds. Having sufficient volume in settlement ponds would reduce the need for lining the canals.
6. The company should invest in finding ways to sell its sediments to others. It could then turn a waste product that costs the company a considerable amount for treatment and disposal to a revenue-neutral product, if not a revenue generator.
7. Given the importance of maintaining disease-free stock, it is very important to build firewalls between the hatchery and the grow-out operations. The ponds used for development and maturation of broodstock should be physically distant from grow-out ponds. This could limit the spread of any disease within the system. If possible, it might also be good to separate the broodstock maturation facilities from the hatchery and post-larvae facilities, for the same general reasons.
8. Belize Aquaculture may be tempted to take the information that they have gathered thus far and simply apply it on a larger scale. In our opinion, this would be a mistake. There are still too many unknown variables about the current system. Furthermore, the best management practices and systems are adaptive, learning systems. For this reason, we recommend that the grow-out ponds also include a number of smaller ponds where different field trials and experiments can be undertaken. Such experimentation is one of the main reasons for the success to date of Belize Aquaculture. It would be a mistake to abandon it now, especially when the stakes could be so much higher.
9. Currently, the pond configuration allows brackish water to be added to reduce the salinity in the ponds during the dry season. This has not been done to date, and since it is generally not considered a good practice to dilute fresh water with sea water, the company should avoid that practice. To date, salinity ranges from 12 ppt to 41 ppt have had no serious effects on production. However, while modest in comparison to any other aquaculture operations in Belize, the amount of brackish water taken by the company from lagoons needs to be evaluated for any effects on lagoons and other water bodies in the region. Further complicating this issue is the likelihood that other users will be dumping their effluent into lagoons rather than back into the ocean. This practice could cause severe deterioration of water quality and put all users at risk. For Belize Aquaculture, it may simply be cheaper in the long run to rely as much on ocean water as possible.
10. Harvesting in the old system was undertaken with one machine through one opening in the pond. There are three harvesters in the new farm and all systems have been backed up. The flow of water from the old system took too long. That meant that the final animals were severely stressed from the lack of oxygen. This problem was avoided in the new system by having two drains and thus speeding up the time it takes to drain the pond. This also can be a more efficient use of labor. Finally, being able to harvest more quickly allows the harvesting to be spread out somewhat, so that any emergencies or problems have fewer impacts.
11. The expansion of the system will require different types of labor organization, allocation, and management methods. The company is now very small, and everyone knows everyone else. This will change. Management systems need to be in place.
12. Labor specialization has been considered as a way to meet anticipated needs. One team, for example, could be responsible for feeding, one for maintenance, one for harvesting, and so on. One reason the current system works well, however, is that employees do many different tasks and for that reason are aware of changes that they might not notice otherwise. Avoiding problems of myopia that might arise from specialization could be accomplished by rotating teams. Another method is to make teams responsible for every function in a certain location. This latter method lends itself to using incentives, whereas the former does not. In Latin America, incentives that in other parts of the world have proven very useful in increasing production, reducing costs, and

increasing net returns have been adopted very slowly, if at all. Incentive-based production is one of the most promising areas for improving performance in a company like Belize Aquaculture.

13. It may be hard to find enough people with the skills and motivation to provide the needed labor. This situation is aggravated by the isolation of the farm; most of the educated people in Belize live in the cities. In any case, the company's growth will increase the population in the area and could have social and environmental effects, particularly if the workers are not from the region or even from Belize.
14. During the pilot phase, Belize Aquaculture experienced instances of inadequate redundancy or infrastructure. While this is the norm in startups, such occurrences should be avoided as the operation expands. The new operation has built in redundancy. This is good because capacity should exceed known need since extra capacity sometimes makes the difference between profit and loss. The company now has backup motors, tires, containers, and other equipment as well.

Socioeconomic Aspects of Belize Aquaculture's Production Methods

A number of socioeconomic issues are raised by Belize Aquaculture's production methods. Perhaps the most obvious is whether the current system, or any based on it, can provide beneficial opportunities for a wide range of stakeholders. Currently, the expanded system proposed by Belize Aquaculture would cost approximately $250,000 per hectare to develop. It is possible that the actual figure might be reduced to as much as $80,000 through efficiencies of scale. However, even this sum is well beyond the means of most people in the world to invest.

One question is whether the current system can be broken down into smaller units that could be managed by individuals or families. The development cost of the system could perhaps be reduced to $80,000 per acre. However, even this amount of money is far too much for poor families unless credit is extended and investment funds created to assist them.

By eliminating the costs of hatcheries, processing plants, and generating energy, it may be possible to reduce the up-front costs of developing shrimp production facilities like Belize Aquaculture to about 50% of the projected cost. Some of the material could be made in-country and labor could substitute for some of the other fixed costs as well. Even so, these operations will be expensive. It is hard for small investors to borrow money if they lack assets to use as collateral. Government could intervene as a loan guarantor, but this has not tended to work in the past in other developing countries. It is more likely, however, that processing plants and export facilities, or even large growers, might be persuaded to work with an association of smaller producers if a mutually advantageous approach can be identified.

Of course, the current system does generate jobs. In fact, while the per-kilo labor demand is less in Belize Aquaculture's operations than in traditional systems, the per-hectare direct and indirect job creation is greater due to the higher production, intensity of inputs, and processing. These shrimp farm workers earn more than they would in other commercial or subsistence agriculture, so these jobs have an additional positive impact. Worker training will also increase, likely creating a spillover effect in the local area and the country as a whole. Whether this would be true in other countries is another issue; it could just mean an influx of skilled workers.

The development of worker incentive and worker equity programs provides ways to increase the positive socioeconomic impacts of the system. Worker incentive programs appear to be worthwhile, from experience in other parts of Latin America. Employee stock option programs (ESOPs) have not been developed in the shrimp aquaculture industry, although they appear to hold promise in plantation agriculture and other similar large-scale, labor-intensive operations.

The ultimate success or failure of shrimp farming in general depends on the industry's ability to reduce inputs and waste and thus to achieve greater efficiency in their overall operations. Belize Aquaculture is no exception. In fact, due to the intensity of the operation, a small increase in efficiency there can generate more gross income per hectare than many traditional semi-intensive shrimp operations earn in the course of a year.

One example of increased income from efficiency measures comes from recycling water and virtually eliminating down time for pond preparation. Belize Aquaculture has 2.4 harvests per year. The plastic liners in the ponds allow the company to avoid drying out the ponds and treating the soil. If the company saves 5 days per crop, that means 12.5 days per year saved. This in turn translates to about 9% more crops, or 1,200 kg/ha more shrimp per year.

Similarly, reusing water allows management to restock ponds more quickly than if new water had to be conditioned before it could be stocked. In Belize, it takes about 10 days to condition water before stocking. If Belize Aquaculture can avoid this step entirely, they would have 24 more days of production per year (10 days each, for 2.4 crops/year). This in turn could translate to approximately an 18.5% increase in production. With current production averages, that would amount to some 2,516 kg/ha/year, or some $10,000 of gross income per hectare. This is more gross income per hectare per year than many shrimp farmers in Latin America make in total at this time.

In fact, the conditioning of water probably takes more than 10 days. For example, there is less plankton in the existing conditioned water. The pH is relatively stable at 7.2 to 7.4, sometimes even as low as 6.8. Fresh water often starts at pH 8.3 and requires 10–12 weeks to get to a level of 7.4. Thus, it takes the water nearly three months to get to the pH level of the recycled water. During this entire time, shrimp are slightly stressed, and their survival and "thriving" (weight gain) rates are likely to decline.

Similarly, fresh, or new, water often has an oxygen level of 9 in the afternoon compared with 5.5 in the morning (probably because phytoplankton blooms produce oxygen during the day). In ponds with recycled conditioned water, the daytime oxygen rates are about 5 to 5.5 in the afternoon and 4.5 in the morning. It is quite possible that the more stable oxygen levels, though lower on average, produce better growth rates.

Shrimp survival rates in Belize Aquaculture first improved from 65% to 78%; the use of AquaMats™ has allowed Belize Aquaculture to further increase the survival rate to 91%. The increased survival rate and the increased feed conversion ratio (from 2:1 to 1.4 or 1.3:1) together have allowed the company to increase production by 1,550 kg/ha/year. This compares to the cost of installing AquaMats™ at $11,250 per hectare.

Production efficiencies are often compounded. Increases in the survival rate indicate not only increased numbers at harvest but also greater efficiency throughout the production cycle. Higher survival rates also lead to more efficient feed utilization, for example. Shrimp tend to be overfed because it is impossible to determine how many shrimp may have died after stocking. Overfeeding, in turn, causes a deterioration of water quality, increased stress, and the death of animals. Higher survival rates tend to avoid such feedback cycles. The impact on net profits from working capital is even greater as inputs are used more efficiently. Finally, the income generated relative to fixed capital investments and productive assets is also improved as more gross income is amortized over the same value of assets.

While the intensity of the operation and the attempts to close the production system in a number of important ways help to limit its environmental impact, there are some environmental issues that should be noted, especially if the system is expanded on a grand scale. First, there is the issue of the carrying capacity of any region where shrimp aquaculture is being undertaken. It is important to understand and monitor carrying capacity, as more and more operations are being planned and permitted. The cumulative impact of these operations needs to be anticipated, and when it is not well understood, a precautionary approach should be used, not only to protect the environment but also the existing investments of others already established in the area—whether for shrimp farming or other purposes.

Carrying capacity issues include sources of clean water as the industry expands. Another issue is the ability of traditional systems to dispose of effluents in ways that do not pollute local water bodies or foul their own intake supplies. While water pollution does not appear to be a problem, the disposal of sludge from the shrimp operation could become as much of a problem for Belize Aquaculture as the disposal of chicken manure is for intensive poultry operations in United States. Simply spreading the material on land is a limited solution.

There are also issues of carrying capacity for infrastructure (e.g., roads, schools, clinics, and electricity). Social systems in isolated rural communities can be swamped by the immigrant labor needed to staff operations such as Belize Aquaculture. This is true of the hatchery and processing plants as well as the grow-out operations. The absorption capacity of these systems can often be exceeded, leading to considerable conflict and hidden (and not so hidden) costs for all affected, especially if a "gold rush" mentality takes over in the context of rapidly expanding shrimp aquaculture.

Conflicts over resource use may also arise. The lined-pond production system developed by Belize Aquaculture can be used on any stable soil that is in the right climate zone and within pumping distance of water supplies. It is quite possible that such systems will be located farther from the ocean and that they could begin to compete with other land uses. If this happens, it is extremely important to ensure that the systems are truly closed so that they do not contaminate freshwater sources above or below ground. It is also important to minimize any potential impact from taking water from rivers or lagoons during the dry season to dilute rising salinity in ponds.

Conclusion

In conclusion, because the system is highly intensive and more "environmentally friendly" than traditional aquaculture systems, we are convinced that the Belize Aquaculture production system, or some modification of it, will very likely be the aquaculture system of the future. However, two issues of concern remain. First, all superintensive shrimp aquaculture production systems have failed in the past. It is important that this one be monitored carefully so that as much can be learned about it as possible. Second, as with any good idea, someone will inevitably try to improve on it. It is important that the key elements of this program not be changed in "improved" models. The basic elements that appear to be crucial to the success to date of the Belize Aquaculture system include: small lined ponds, aeration, and disease-resistant omnivorous shrimp species.

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