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Opportunities and Constraints in Marine Shrimp Farming

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Shrimp mariculture, the production of saltwater shrimp in impoundments and ponds, originated in Southeast Asia where for centuries farmers raised incidental crops of wild shrimp in tidal fish ponds. The shrimp were not considered of great value. Time has changed this perspective, and shrimp culture has grown into one of the largest and most important aquaculture crops worldwide. All kinds of shrimp (coldwater and warmwater) are highly desirable now in a world market. Most coastal countries have a harvest industry for shrimp, and about 100 of those catch enough to export. More than 50 countries practice shrimp aquaculture. Shrimp culture increased 300 percent from 1975 to 1985, and 250 percent from 1985 to 1995. If it increases 200 percent between 1995 and 2005, world shrimp culture production will be at 2.1 million metric tons (MT =1.1 standard tons, 2,204.6 pounds or 1,000 kg). According to a report of the Food and Agriculture Organization of the United Nations, world production of farmed shrimp reached 1,130,000 MT of whole shrimp in 1999.

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The major aspects of shrimp mariculture are sourcing or obtaining brood for hatchery production, maturation and reproduction of broodstock, genetic selection, egg and nauplii production, larval rearing, postlarval holding and sales, growout in ponds and raceways, production of bait or edible shrimp, harvesting, processing, and sales to a world market.

Life cycle

Juveniles and adults migrate offshore, and in the stable environment of the ocean they mature, mate, and spawn eggs in offshore waters (Fig. 1). All but one species within the Family Penaeidae follow this life cycle sequence, although the sequences vary greatly among species. Most tropical shrimp eggs are 0.00003937 inches (220 micrometers) in diameter. They hatch within 14 hours at 28 ^{o}C (82.4 ^{o}F). The nauplius is the first larval stage and it is attracted to light. In natural settings, the shrimp postlarvae (PL) are carried by ocean currents to the protection of estuaries, where they have a diet rich in various sources of nutrition. They remain there until the late juvenile or early adult stage.

The growout phase in bays and ponds generally takes 4 to 5 months (16 to 20 weeks), depending on the environmental conditions, species, and, in bays, the timing of migration to offshore areas.

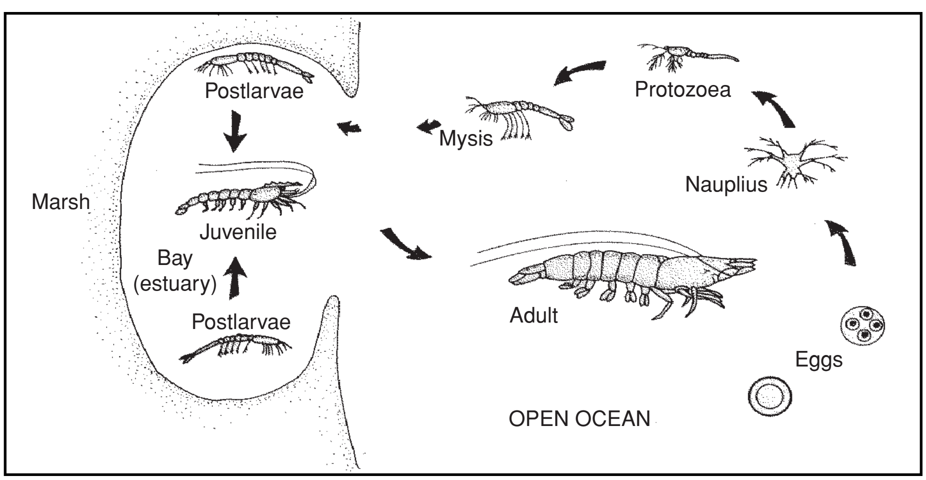

Figure 1. Penaeid shrimp life cycle.

History of marine shrimp farming

In 1933 M. Fujinaga of Japan initiated research on *Marsupenaeus japonicus* (previously known as *Penaeus japonicus*) and opened the door to modern shrimp farming. His work contributed largely to the initial development of the industry. In the 1930s, J.C. Pearson described the eggs of some western hemisphere penaeid shrimp and the life histories of some American penaeids. This was an important step in understanding how to obtain desired results in hatchery and growout procedures. Since adults migrate offshore to the more stable salinities and temperatures of the ocean, where they mature and reproduce, commercial hatcheries found that they had to mimic natural conditions. Hatcheries worked better with higher salinities and cleaner water, whereas growout worked best in the back bays and estuaries with lower salinities.

In the 1940s and 1950s, Robert Lunz at the Bears Bluff Laboratory in South Carolina continued the development of extensive shrimp production. He flooded tidal impoundments when native shrimp populations were migrating, controlled predators, and used water exchange to maintain dissolved oxygen levels. His work refined extensive shrimp farming.

Harry Cook and others at the National Marine Fisheries Service laboratory in Galveston, Texas established the "Galveston Technique" of culturing shrimp larvae, which helped to expand shrimp hatchery technology. Research on the culture of larval shrimp started there in 1959 as part of an investigation into the life history of native shrimp in the Gulf of Mexico. Harry Cook published a generic key to the zoeal, mysis, and postlarval (PL) stages of littoral Penaeidae of the northwest Gulf of Mexico in 1965. Other groups also worked on larval rearing of penaeids in the U.S., mainly in Texas. The Texas Parks and Wildlife Department and some of the universities published works on the subject very early. A significant aquaculture research and development effort continues through the U.S. Department of Agriculture and the U.S. Department of Commerce/NOAA/Sea Grant Program.

The first attempts at commercial shrimp farming in the U.S. occurred in the late 1960s and early 1970s, following the Ecuadorian industry's lead based upon the culture of *Litopenaeus vannamei* and *Litopenaeus stylirostris*. The initial U.S. industry used native species of white, brown and pink shrimp. U.S. researchers found that non-native shrimp from the Pacific coast of Central and South America were easier to culture and more productive in ponds. Gradually, commercial producers in the U.S. concentrated on non-native species such as *L. vannamei*, now the most popular species cultured in the Western Hemisphere.

Significant early contributions from private industry in the U.S. came from Ralston Purina and Marifarms in Florida, and Dow Chemical in Texas. Texas now produces more farm-raised shrimp than any other state—approximately 8 million pounds (3.63 million kg) of heads-on shrimp in 2001. Florida has the largest hatchery in the U.S. It can produce 180 million PL per month, but sends most of them to Honduras for growout.

Once shrimp hatcheries began supplying large quantities of shrimp to farmers, the production of farm-raised shrimp expanded rapidly. Problems with disease and poor water quality in the early 1990s slowed worldwide production for a few years. In recent years, production has been increasing because of new disease control protocols and water recirculation and reuse technologies.

Shrimp hatcheries

The hatchery cycle begins with broodstock. In many hatcheries, females with ripe, egg-laden ovaries (gravid females) are brought from the sea for spawning in captivity. The availability and cost of wild gravid females can fluctuate. Their use precludes genetic selection and complicates efforts to control disease introduction. Thus, to achieve better control, technologies for captive maturation and reproduction have been developed. This has allowed for the establishment of breeding programs for fast growing, specific pathogen-free and/or resistant stocks. Captive maturation is achieved by placing broodstock in large (13-foot, 4-m) diameter tanks at densities of five to seven shrimp per 10.7 square feet (1 m^2). The most important parameters for successful maturation of penaeid shrimp are constant temperature, salinity, pH, light, and good nutrition (Table 1).

Once the gravid female is ready to spawn, it releases eggs into the water, fertilizing the eggs by simultaneous rupturing of the spermatophore. The eggs exit the ovipositors, located at the base of the third pair of walking legs, and sink. In non-grooved white shrimp the eggs brush back against the spermatophore as the female is continuously swimming. If the female stops swimming, or her swimming is interrupted, the eggs may fall straight down and are not likely to be fertilized.

Most cultured adult shrimp produce 150,000 to 200,000 eggs per spawn, depending upon the size of the female. The larger species, such as *Penaeus monodon*, can produce 700,000 to more than 1 million eggs each spawn. After hatching, shrimp develop through several larval stages. The eggs hatch into the first larval stage, called the nauplius. The microscopic nauplius larvae are planktonic and feed on their yolk sacs for 48 hours. The nauplius stage is the best larval stage to ship or trans-

Table 1. Parameters for tropical shrimp maturation and allowable ranges per 24 hours.

Salinity	Temperature	pH	Light	D.O.
27-36 ppt +/- 0.5	27-29 ^{o}C +/- 2 ^{o} (80.5-84.2 ^{o}F)	7.8 +/- 0.2	14 L, 10 D	5 ppm $^{+}$

port. Starting at about hour 36 after hatch, microscopic, single-celled algae and later other minute forms of zooplanktonic microcrustaceans (usually freshly hatched brine shrimp, *Artemia nauplii*) are fed to specific larval stages. The larvae develop through three zoea stages and three mysis stages before metamorphosing into a form more closely resembling a typical shrimp or postlarva. Development through larval stages takes 9 to 11 days from hatching (at 28 °C or 82.4 °F). Some hatcheries shorten the larval time in the hatchery by raising the temperature; however, care must be taken because bacterial problems develop faster at the higher temperatures. The most successful hatcheries control bacteria and other diseases through disinfection and other preventive measures.

One of the most important aspects of the location and functionality of the shrimp hatchery is water quality. Almost all hatcheries require oceanic quality water on a 24-hour basis. Shrimp hatcheries require relatively small tracts of land and are operated in a labor-intensive manner. See Figure 2 for a larval rearing facility.

Figure 2. Larval rearing facility.

Nurseries

Nursery ponds are smaller ponds or intensive raceways that serve as an intermediate phase between the hatchery and the growout ponds. Nurseries can be used to increase shrimp size for stocking growout ponds. They also make more efficient use of the growout production area, allow the growing season to be extended in temperate and subtropical climates, and make it possible to evaluate shrimp and eliminate substandard stocks before stocking growout ponds. The growout ponds are used to produce marketable shrimp. Not all farms use the nursery phase. Many farms stock PL, either from the wild (countries other than the U.S.) or from the hatchery, directly to the growout pond. Whether or not a nursery is used, an acclimation period is normally used to prepare PL for farm conditions.

Growout systems

Growout systems are considered extensive, semi-intensive or intensive according to stocking density and associated management parameters. Large ponds or impoundments may be stocked at low densities, producing crops with little or no supplemental feed and relying on wind or water exchange to manage pond water quality. Semi-intensive ponds are normally somewhat smaller, are stocked at higher densities, and use fertilization, water exchange and supplemental feeding to increase yields. The most technologically advanced culture systems are intensive and were developed in countries such as Japan, Taiwan and the U.S., where wild PL are not readily available and where land and labor are expensive. To justify the high input costs and to maximize returns, high yields per unit area and labor are required. Yields from intensive and super-intensive ponds can range from 3,000 to more than 20,000 pounds per acre per crop (1,361 kg to more than 9,072 kg per 0.4 ha).

At the high stocking densities typical of intensive culture systems, natural food organisms do not supply enough nutrition and the farmer must provide a nutritionally complete ration. Feeding efficiency is crucial, as high quality feeds are very expensive compared to the supplemental feeds used in semi-intensive culture. Farmers routinely pay $0.45 per pound ($1.00/kg) or more for intensive culture feed. This represents 60 to 70 percent of the cost of production. To achieve good feed conversion, feeding trays are often used to measure consumption continuously.

In addition to the expense of extra feed, intensive farmers incur the cost of controlling water quality. The pond bottom is easily fouled by the heavy organic load from high feeding rates. These costs are part of the capital and operating expenses to build smaller, more manageable ponds, install pumps and wells to allow for high rates of

Table 2. Shrimp growout comparison table.

	Extensive	Semi-intensive	Intensive
Stocking density (Shrimp/m^2) (Shrimp/10.7 ft^2)	1-10	10-30	>30
Pond size (hectare)	5-20	1-10	<0.5
Aeration (hp/ha)	None	0-2.5	>2.5
Production rates (kg/ha/crop) (-lbs/ac/crop)	100-1,000	1,000-3,000	>3,000

water exchange or recirculation, and use of mechanical devices to circulate and aerate the water.

The cost per pound to produce shrimp generally rises with higher culture intensity, because of increased stocking densities, feeding rates and water quality management efforts. The most cost-effective production strategy for any particular farmer depends on the size of the initial capital investment, the cost of available inputs, (feed, PL, labor, fuel, power, etc.), the availability of suitable sites, and the potential cost savings from economies of scale relative to the total area under culture.

Water quality

Maintaining good water quality in ponds is crucial for success. Table 3 is a compilation of water characteristics for shrimp culture from various sources.

Harvesting

Three crops per year are possible in a warm climate, although most farms in the tropics average 2.6 crops on a year-round basis. Production levels during the cooler months will not be as high, and time is needed to treat pond bottoms between crops. Southern U.S. shrimp farms average 3,500 to 6,400 pounds per acre per crop (1,588 kg to 2,903 kg per 0.4 ha) of heads-on shrimp, which generally fall into the 26- to 30- or 31- to 35-count tail sizes (number of shrimp per pound). Most farms have one crop per year. Harvests are generally conducted with an automated harvester. The harvester (Fig. 3) is usually mounted on a trailer and can be moved from pond to pond. Magic Valley Heliarc makes one of the most commonly used "fish pumps" for harvesting shrimp.

Other production methods

Bait shrimp

A number of research and development projects and commercial attempts to raise shrimp for bait have occurred in the U.S., and some continue today. Research has demonstrated the potential for bait shrimp culture, but due to regulations the industry is limited to producing only native shrimp for use in the waters of the U.S. The availability of native PL for stocking is a problem in developing the industry. Native species do not grow as quickly as non-native species. There is a finite market for live bait shrimp and harvest and post-harvest handling of a live product is much more difficult. To date there are no large, sustainable, economically viable bait shrimp producers in the U.S.

Impoundment production

Coastal wetland impoundments are used to produce penaeid shrimp in extensive culture systems. They use natural stocking or hatchery reared stock. With only natural stocking, yields are low (<100 pounds per acre, <100 kg/ha) on large acreages. Stocking hatchery-reared shrimp and providing supplemental feed increase production in wetland impoundments to 1,000 pounds per acre (~1,000 kg/ha) in certain commercial management regimens. To be economically viable, such operations must use existing impoundments, few of which are suitable for shrimp production.

Super-intensive raceways

The production of shrimp in super-intensive raceway systems (Fig. 4) has many potential advantages. These systems make temperature control easier, making them applicable in subtropical and temperate zones. Super-intensive production must be done on a large scale to be profitable where land, labor, energy and capital costs are high. Super-intensive culture can be coupled with the latest technologies in water reuse to expand production to areas other than expensive coastal land. Furthermore, these systems can be designed to alleviate the environmental concerns associated with shrimp culture. Promising research and small-scale production suggest that these technologies may be successful on a larger scale in the near future. However, super-intensive systems rely on high market prices and, thus, have greater economic risk.

Inland brackish water and freshwater production

Inland farming of marine shrimp, using brackish water, is being done successfully on a commercial scale in Texas, Alabama and Arizona; however, specific water quality parameters of saline groundwater are of extreme importance in the selection of successful sites. Florida is also attempting the commercial culture of marine shrimp using "fresher" ground waters. The brackish water operations have operated successfully for several years and expanded. In Arizona, extremely low salinity effluents from ponds are used in integrated systems as a rich source of water for irrigating winter wheat and table olives. Saline effluent in other states is used in either on-site hold-

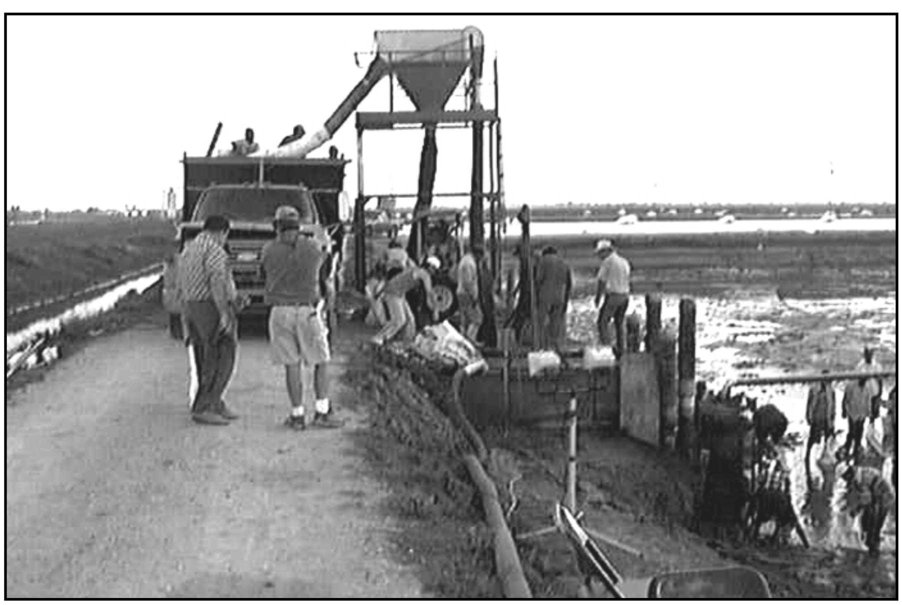

Figure 3. Shrimp harvester.

Table 3. Water characteristics for shrimp culture. (All parameters in ppm [mg/L] unless noted otherwise).			
Variable	**Form in water**	**Desired concentration**	**Notes**
Boron	Borate (H_3BO_3, $H_2BO_3^-$)	0.05 –1	See [1]
Cadmium (Cd)		<0.1	
Calcium	Calcium ion (Ca^{2+})	100 - 500	
Carbon dioxide	Dissolved CO_2 Gas	1 - 10	
Chloride	Chloride ion (Cl^-)	2,000 - 20,000	
Copper			
	Copper ion (Cu^{2+})	<0.0005	See [1]
	Total Copper	0.0005 - 0.01	
Iron			See [1]
	Ferrous iron (Fe^{2+})	0	
	Ferric iron (Fe^{3+})	Trace	
	Total iron	0.05 - 0.5	
Magnesium	Magnesium ion (Mg^{2+})	100 - 1,500	
Manganese			
	Manganese ion(Mn^{2+})	0	
	Manganese dioxide (MnO_2)	Trace	
	Total manganese	0.05 - 0.2	
Molybdenum	Molybdate (MoO_3)	Trace	
Nitrogen	Dissolved N_2 Gas		
	Molecular nitrogen (N^2)	Saturation or less	
	Ammonium (NH_4^+)	0.2 - 2	
	Ammonia (NH_3)	<0.1	
	Nitrate (NO_3^-)	0.2 - 10	
	Nitrite (NO_2^-)	<0.23	
Oxygen	Dissolved O_2 Gas	5 - 15	See [2]
pH	H^+[-log(H^+)=pH]	pH 7 - 9	See [3]
Potassium	Potassium ion (K^+)	100 - 400	
Salinity		5,000 - 35,000	See [4]
Sodium	Sodium (Na^+)	2,000 - 11,000	
Sulfur			
	Sulfate (SO_4^{2-})	500 - 3,000	
	Hydrogen Sulfide	<0.02 (preferably not detectable)	
Suspended Solids		<100	
Temperature		26-29 ^oC (78.8-84.2 ^oF)	See [5]
Turbidity			See [6]
Zinc			
	Zinc ion (Zn^{2+})	<0.01	
	Total zinc	0.01 - 0.05	

Notes:

[1] The desirable ranges for these substances are poorly understood. The values listed as the desired concentrations are actually the usual concentrations of these trace metals in surface waters.

[2] O_2 for growth, 2-3 ppm minimum.

[3] pH directly influences shrimp (pH of 4 = acid death point; 4-5 = no reproduction; 4-6 = slow growth; 6-9 = best growth; 9-11 = slow growth; 11 = alkaline death point).

[4] Salinity is normally referred to in parts per thousand or ppt (5,000 - 35,000 ppm = 5 - 35 ppt). 35 ppt is generally considered a normal salinity for open ocean water. Some shrimp can grow in salinities outside these ranges.

[5] Temperature for tropical shrimp. For growth, 23-25 ^oC (73.4-77 ^oF) minimum, and 33-34 ^oC (91.4-93.2 ^oF) maximum.

[6] Turbidity (Goal is Secchi disk reading of 25-40 cm (10-16 in.) and water color of yellowish-brown).

Figure 4. Super-intensive raceway system for shrimp.

ing ponds or reused in adjacent catfish ponds. In inland systems, saline effluent will remain a major issue as more restrictions on aquaculture effluent evolve.

Economics of producing shrimp in ponds

Shrimp are produced in ponds, raceways and tanks. Production costs vary from $2.50 to $5.00 per pound. Feed, larvae and processing are the three highest variable costs. It generally takes 2 pounds (0.91 kg) of feed to produce 1 pound (0.45 kg) of shrimp. The main economic problems with culturing shrimp in the U.S. are:

- availability of low-cost, high quality feed,
- short growing season (one crop only in some areas because of temperatures),
- high land, labor and operating (power, etc.) costs,
- foreign competition, and
- price fluctuations.

Shrimp producers generally contract with a processing plant to ice, de-head, grade, pack, freeze in plate freezer, and keep shrimp for 1 month in cold storage. Processors charge an average of $0.63 per pound ($1.39/kg). About 40 percent of a shrimp's weight is in the head. Production in ponds often ranges from 2,000 to 8,000 pounds per acre per crop in the U.S., with an average crop of 3,500 pounds per acre.

A 20 percent profit margin is considered good in this high-risk industry. Profit margins have been narrowing because of rising feed, labor and fuel costs and new discharge regulations have hurt the farms because more money is needed to install new recirculation pumps, etc. Market prices for shrimp were down in 2001, which also contributes to the risky nature of the industry.

Costs for a pilot shrimp farm in south Texas are shown in Table 4. The farm consists of four 5-acre (2-ha) ponds, with a settling basin attached to each pond and one common 14.8-acre (6-ha) constructed wetland. A total of 50 acres is needed for this facility. The facility is now in operation and was designed to treat water on-site and to discharge water only during harvest. The farm takes in water only to fill ponds and offset evaporation and other water loss, and the facility is capable of producing 36 MT of shrimp per year (approximately 4,000 pounds per acre). The average construction cost for the 50-acre (20-ha) facility was $9,191 per acre ($22,978/ha).

Marketing

Shrimp are generally sold to the processing plant. The average farm-gate price in Texas in 2000 was $3.40 per pound ($7.71/kg) for head-on shrimp (18-gram or 25-count = 25 shrimp per pound). One farm has its own processing plant that de-heads the product and individually quick freezes (IQF) the tails in 5-pound (2.268-kg) clear plastic freezer bags. This product sells for about $5.90 per pound retail ($13.38/kg) at the cold storage facility, which is also owned by the farmer. Most farms either sell to the plant or have the processing plant de-head the product, blast-freeze the tails, pack them in 5-pound (2.2-kg) waxed boxes with the plant's or the farm's label on the box, and hold the shrimp for 1 month as part of the processing cost. There are a number of seafood wholesalers and seafood buyers who purchase the product and pass the shrimp through the U.S. marketing channels. Shrimp prices are available on the internet at *http://www.st.nmfs.gov/st1/market_news/doc45.txt*.

Major constraints

Of all natural products, seafood contributes more to the U.S. trade deficit than any other product except oil. When all products are considered, seafood is fourth after oil, automobiles and electronics. Growing populations along the coasts are placing extra burdens on coastal environments. Seafood safety is an issue as environmental degradation continues. The Hazard Analysis Critical Control Point program (HACCP) begun in December, 1997, placed additional controls upon the seafood industry (see *http://vm.cfsan.fda.gov/~dms/haccp-2a.html* for more information). With limited entries, by-catch controversies, and turtle-free and dolphin-free industry requirements, the wild-caught seafood industry has little opportunity to expand. New environmental regulations on our coasts also constrain aquaculture.

Disease risks

Shrimp diseases have also constrained the industry. Shrimp

Table 4. Costs for a pilot shrimp farm in Texas.

	Price in US $
Contractual	
Construction management, equipment operator & rental	20,045
Earth moving	72,982
Electricity establishment (includes electricity to aerators)	25,000
Fencing (1,500 meters or 5,000 feet installed)	10,815
Insurance, repairs and maintenance, dues, water analysis, misc.	6,000
Legal fees (permitting, etc.)	50,000
Supplies	
Wetland vegetation, truck fuel, grass seed, tools, misc.	18,400
Pipe, lumber, hardware	20,073
Equipment	
Land (50 acres @ $1,500/acre or 20 hectares @ $3,750/ha)	75,000
Pumps	5,000
Feed equipment: pond feeder, bulk bin (8-ton)	10,770
Aerators, controllers and wire (60 @ 2 hp each) ($476 each)	28,565
Emergency aerator	4,449
Tractor (used, 140 hp), truck (used, 3/4-ton, 4wd)	25,000
Electrical generator (pto driven, 50 kva)	5,000
Drains, harvest basins	7,953
Scraper blade, mower	4,000
Screens, nets, pl acclimation equipment	3,500
Trailer & furniture (office, storage & occasional housing)	11,000
Water quality lab equipment	8,500
Repairs, contingencies, misc.	11,000
Personnel	
On-farm labor, consultants	36,500
Total costs	**$459,552**

Source: Ronald Rosati, Texas A&M University—Kingsville.

viruses, in particular, can devastate shrimp in crowded culture conditions. But genetic selection programs such as the one conducted by the USDA's Marine Shrimp Farming Program have made progress in producing shrimp stocks that are more resistant to diseases. For example, the USDA has developed genetically improved stocks that are resistant to the Taura Syndrome Virus. Genetically superior shrimp are held in quarantine in Hawaii and their offspring are sent to U.S. hatcheries. However, as more research on shrimp diseases has been conducted, more diseases have been identified. Biosecurity measures and regulatory constraints on PL shrimp for stocking reduce the possibility of introducing diseases, but if broodstock come from surface water sources, the possibility is always real.

Weather

Weather in the U.S. also constrains shrimp aquaculture. Cold weather, drought and hurricanes are the primary concerns. In October 2000, extreme cold contributed to the loss of 1.5 million pounds (680,000 kg) of shrimp on Texas shrimp farms. The climate allows one long crop or two short crops during the summer months (generally from April to October).

Non-native introductions

Litopenaeus vannamei is the most common exotic or non-native shrimp used in the U.S. Some releases of these shrimp have occurred at harvest in the past, but strict regulations now prevent their accidental release into the environment. Pond discharges must be double- or triple-screened to prevent the escape of non-native shrimp into the natural environment. A number of groups still object to the introduction of non-native species and farmers must be ever mindful of the possible restriction on the use of non-native species if they escape and ecological problems develop.

Discharges

There are very strict regulations for shrimp farm discharges. Stricter environmental regulations and the desire to control the spread of shrimp diseases have forced some of the farms to recirculate water. Based in part on research at South Carolina's Waddell Mariculture Center, farmers have learned to produce shrimp using far less water than ever thought possible. One Texas farm is producing more than 1.4 million pounds (637,435 kg) of shrimp on 345 acres (139 ha) or about 4,000 pounds per acre (4,481 kg/ha) in a semi-closed system. The farm cut its water use from 4,500 gallons per pound (37,561 L/kg) of shrimp produced in 1994 to 300 gallons per pound (2,504 L/kg) in 1998-2001. Most of the water is used to fill the ponds and offset evaporation. Most farms also have cut stocking density from 50 to 36 shrimp per 10.7 square feet and increased aeration from 8 to 10 hp per acre (20 to 25 hp/ha). Some farms use as much as 16 hp per acre (40 hp/ha) if they recirculate water through wetlands. Other farms have developed adjacent shellfish ponds, which serve as settling ponds and act as natural filters while producing a secondary crop. Some farms have widened and deepened their discharge canals and aerate them. As a result of these changes, the Total Suspended Solids (TSS) discharged on intensive farms dropped from 3.6 pounds (1.6 kg) per pound of shrimp in 1994 to 1 pound (0.45 kg) per 20 pounds (9kg) of shrimp in 1998. Over the same time period, farms reduced:

- ammonia from 0.05 pounds per pound of shrimp to 1 pound for every 2,500 pounds of shrimp (0.45 kg ammonia per 1,125 kg of shrimp);
- carbonaceous biochemical oxygen demand from 0.1 to 0.17 pound (0.045 to 0.008 kg) per pound of shrimp to 1 pound (0.45 kg) for every 100 pounds (45 kg) of shrimp

These farms have also maintained production at more than 4,000 pounds per acre (4,481 kg/ha) of shrimp since 1994. The development of environmentally sensitive management techniques is ensuring the future of sustainable shrimp farming in U.S. coastal areas. In 2000, the U.S. Environmental Protection Agency began reviewing aquaculture effluents with the goal of improving discharge regulations in the aquaculture industry. Any new regulations are to be based on scientific data and directed at implementing economically viable, technology-based solutions for improving the quality of aquaculture effluent. The regulations, if changed, will certainly increase the cost of production and restrict the development of the industry.

Hatchery constraints

Almost all marine shrimp farms in the U.S. stock non-native *Litopenaeus vannemei* because they grow better and have better feed conversion than native species. Only a few shrimp hatcheries meet the USDA Marine Shrimp Farming Consortium guidelines as sources of non-native PL for shrimp stocking, so there has often been a shortage of PL during the brief U.S. stocking season. When PL are in short supply, some farms can stock only at certain densities and on certain stocking dates. Any loss of production from the few hatcheries that exist can make a tight PL supply even more restrictive to the industry.

Conclusions

Opportunities for marine shrimp aquaculture in the U.S. are expanding, but there are many constraints and the risks are high. In states where the stocking of non-native shrimp is allowed, the industry has grown. Regulations on non-native introductions and discharge are a burden to the industry, but through research and Extension programs the industry continues to progress. Shrimp farming, like any new animal production industry, has high risks. U.S. shrimp farming also must compete with a highly productive international industry and with other development interests for valuable coastal sites.

Suggested reading

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