CULTURE OF

FRESHWATER PRAWNS

IN TEMPERATE CLIMATES

MANAGEMENT PRACTICES AND ECONOMICS

Culture of Freshwater Prawns in Temperate Climates: Management Practices and Economics

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INTRODUCTION

Commercial production of freshwater shrimp or prawn (*Macrobrachium rosenbergii*) has been the subject of research and commercial enterprise in the United States for several decades. This species is native to the tropical Indo-Pacific region of the world. Basic production techniques were developed in the late 1950s in Malaysia, and in the United States, Israel, and several Asian countries during the last three decades. In 1984, the Mississippi Agricultural and Forestry Experiment Station (MAFES) initiated an extensive research program to develop and evaluate management practices for the establishment of a commercial freshwater prawn industry as a supplement or alternative to the culture of channel catfish, an established industry.

This bulletin is based upon the results of research efforts during the past 16 years and provides a detailed description of the management practices for the three phases of culture (hatchery, nursery, and pond growout) of the freshwater prawn in temperate climates. Important information concerning the biology of the species as well as supplies and equipment necessary for successful culture is also presented.

The prospects for an economically successful prawn industry in certain regions of the United States have increased dramatically because of the development of improved management practices that have been successfully applied to commercial production systems. These production practices, for the first time, efficiently manage the unique biology of the prawn.

LIFE HISTORY

Growth

Freshwater prawns, like all crustaceans, have a hard outer skeleton or shell that must be shed (molting) regularly for growth to occur. Increases in body weight and length of the prawn principally occur soon after completion of each molt. Growth is therefore incremental rather than continuous.

Breeding

Females generally become reproductively mature by 6 months of age. Mating occurs only between hard-shelled males and soft-shelled females (i.e., mature females that have just completed a molt). The male deposits sperm held within a gelatinous mass underneath the body of the female between her fourth pair of walking legs.

Within a few hours after mating, spawning occurs through the release of eggs that are fertilized by the sperm and then transferred and attached to the underside of the abdomen (tail) in a "brood chamber" formed by the abdominal swimming appendages. The eggs are aerated and cleaned by movement of these appendages and remain attached to the abdomen until they hatch. Mating and spawning can occur in either freshwater or brackish water.

As long as water temperature exceeds 21°C (70°F), multiple spawns per female can occur annually. The number of eggs produced at each spawn is directly proportional to the size of the female. Females carrying eggs are often termed "berried females."

The rate of egg maturation and eventual hatching increases as water temperature increases. At a tempera-

ture of 28°C (82.4°F), the eggs hatch approximately 20–21 days after spawning. The bright yellow color of newly spawned eggs gradually changes to orange, then brown, and finally to gray about 2–3 days before hatching. Newly hatched freshwater prawns then enter into a larval phase.

Larvae

When larvae are released after hatching, they swim upside down and tail first. The larvae cannot survive in freshwater beyond approximately 48 hours and require brackish water for growth and development to continue. In the wild, hatched larvae are transported down rivers to brackish coastal water. Larvae are very aggressive sight feeders that feed almost continuously, and their natural diet primarily consists of small zooplankton, large phytoplankton, and larval stages of other aquatic invertebrates. Larvae undergo 11 molts, each representing a different stage of metamorphosis primarily characterized by changes in the morphology (form) of the body. Following the last molt, larvae transform into postlarvae. The duration of time necessary for transformation from a newly hatched larva to postlarva depends upon quantity and quality of food, temperature, light, and a variety of other water quality variables.

Postlarvae

After metamorphosis to postlarvae, the prawns resemble miniature adults, having a total body length of 7–10 mm (0.3–0.4 in) and weighing 6–9 mg (50,000–76,000 prawns per pound). During the early part of the postlarval phase, the behavior of the prawns changes from free-swimming and inhabiting the water column (pelagic) to crawling principally and inhabiting the bottom (benthic). When swimming does occur, the movement is adult-like — with the dorsal (back) side up in a head-forward direction.

In the natural environment, postlarvae tolerate a wide range of salinities and eventually migrate up river to freshwater. In addition to the food they ate as larvae, their diet now includes larger pieces of both animal and plant material such as larval and adult aquatic insects, algae, mollusks, worms, fish, and feces of fish and other animals.

Postlarvae are translucent, and as they grow, they gradually take on the bluish-green to brownish color characteristic of the adult stage. The term "juvenile" generally refers to individuals that are several weeks beyond postlarvae in age but have yet to reach the adult stage. However, no standard definition for the juvenile stage exists.

Adult

Older juveniles eventually enter into the adult stage and usually have a distinctive blue-green color, although sometimes they may take on a brownish hue. Color is influenced by the quality of diet. Identification of adult males and females is easily accomplished through examination of the ventral (bottom) midbody region of the prawn. The base of the fifth or last pair of walking legs (periopods) of males is expanded inward to form flaps or clear "bubbles" that cover the openings (gonopores) through which sperm are released. In females, the gap between the last pair of walking legs is much wider and a genital opening is located at the base of each of the third pair of walking legs.

Three different forms (morphotypes) of adult males have been identified based upon external and physiological characteristics. Easily distinguishable are the blue claw (BC) males that are characterized by long, spiny blue claws. Two other male morphotypes are orange claw (OC) and strong orange claw (SOC). OC males sequentially transform to SOC and then to BC males, but the actual conditions that cause transformation after the occurrence of a molt are not completely defined. Some OC males in the population are characteristically smaller than other males (often referred to as small males) in the population due to comparatively slower rates of growth. Although these males are small, they are reproductively mature and play a greater role than other OC males in reproductive activities.

Males that mate with females are restricted to BC males and some of the smaller OC males that are reproductively mature. Only the BC male maintains a territory associated with a group of females that are ready for mating. He protects this "harem" of females, particularly during a postmolt period when they are vulnerable to cannibalism. As the age of BC males increases, reproductive capacity diminishes. BC males undergo an extended period of nonmolting (anecdysis) when no growth occurs. Eventually, the BC male will molt and return to a growth phase during which its reproductive capacity is gradually renewed.

The three phases of freshwater prawn culture are hatchery, nursery, and pond growout. Initial planning and operation of a prawn production enterprise should temporarily forego the hatchery phase and possibly the nursery phase. Although the hatchery and nursery phases are comparatively shorter, future investment of time and money should be based on achieving success repeatedly in the pond growout stage. Any plans for development of a nursery and possibly a hatchery phase of production should be approached with careful planning. Nursed juveniles for stocking into growout ponds can be purchased from a supplier. A limited number of suppliers of juvenile prawns currently exists, and an increased demand will lead to the establishment of more enterprises that exclusively produce postlarvae and juveniles (analogous to producers of fingerlings for stocking production ponds in the catfish industry).

Hatchery/Seedstock

Procurement of Seedstock

Production of juvenile freshwater prawns for stocking into growout ponds begins with maintenance of a healthy broodstock population. In temperate climates, prawn broodstock are generally selected from the crop harvested from ponds and then transferred to tanks or raceways located within a temperature-controlled building. Water temperature for broodstock holding should range between 25°C and 28°C (77°F and 82.4°F). Broodstock are generally stocked at a density of 19 prawns per liter (1.15 oz/gal) in a ratio of 10 females to 2–3 males. If you plan a 4- to 5-month holding period before collection of egg-bearing females for larval production, then you must include 3–4 OC males for every BC male. Feed broodstock a high-quality diet containing at least 35% crude protein; a high level of energy, 3 kcal/g (85 kcal/oz); and at least 0.5% highly unsaturated fatty acids (a commercially available salmonid fish diet would be suitable). The feeding rate should be equivalent to 1–3% of the prawn's body weight per day. Divide that amount of feed into two separate feedings of equivalent amounts. Equip tanks or raceways that hold broodstock with structures that allow maximum use of the entire water column. A few weeks before the eggs are near hatching, feed broodstock a supplemental beef liver at an equivalent ration on a dry weight basis (moisture content of beef liver = 80%). Cut frozen beef liver into half-inch pieces and rinse with water to remove excess blood that might cause fouling of the system.

A mature female produces approximately 500 eggs per gram of live body weight (14,000 eggs per ounce). At the previously stated recommended range of holding temperature, normal egg development is characterized by a series of color changes from bright yellow to orange to brown to a gray-green. Gray-green eggs generally hatch within 24–72 hours. To remove females that hold eggs that are about to hatch, partially drain holding tanks and directly transfer selected females to special hatching tanks (Figure 1) that contain water of similar temperature. Salinity of the water in these hatching tanks should be 0–5 g/L (parts per thousand [ppt]). Larvae usually hatch from eggs at night and are attracted to light. Place a low-intensity light above the overflow pipe of the hatching tank to attract the larvae, and they will flow into a separate, adjoining collection tank. Position a small mesh screen — 90–120 μm
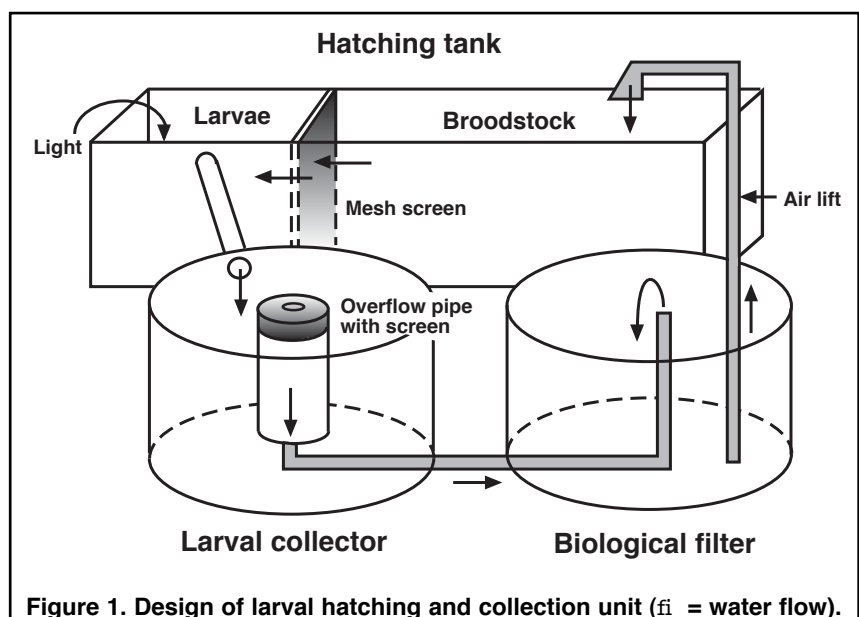

Figure 1. Design of larval hatching and collection unit (fi = water flow).

(3.5x10^{-5} to 4.7x10^{-5} in) — around the overflow pipe of the collection tank to prevent larvae from escaping. Water from the collection tank then flows either into another tank or returns to the hatching tank.

On the following day, determine the concentration of larvae (number per liter) in the collection tank. Then, remove the appropriate number of larvae for stocking into tanks for the hatchery phase of culture. The recommended initial stocking density for hatchery culture is 50–80 larvae per liter (189–300 per gallon). Larvae should be collectively stocked only from hatches that occurred within a 1- to 3-day interval. Before stocking a new batch of larvae, feed the previously stocked larvae so that they have at least partially full guts. This procedure minimizes the incidence of cannibalism of late-stocked larvae by larger larvae that were stocked earlier, and it ensures that a narrow range of larval stages exists at any time during the culture period. Maintenance of a narrow range of larval stages (sizes) also minimizes the duration of the harvest of postlarvae.

Culture Conditions

Larval culture must be conducted in tanks that receive indirect sources of natural light with intensity equivalent to a typical late morning or early afternoon on a partly cloudy to clear day. During the early morning and late afternoon, complement the natural light with intense artificial light. However, never use artificial light as an exclusive substitute for natural light.

For larval culture, we recommend "clearwater" (minimal algal growth) recirculating systems (Figure 2) with water at a temperature of 28–30 °C (82.4–86 °F) and a salinity of 12–15 g/L (ppt). Use of recirculating systems, whether located inland or along a coast, provides for efficient use of water and reduction of heating costs. Water in the larval culture system is pumped from a collecting reservoir (sump) through a sand filter, and then through an ultraviolet light unit and a biological filter before it enters into the larval culture tank (Figure 2).

The biological filter is required to remove certain nitrogenous waste products (ammonia, nitrite) that can be toxic if allowed to accumulate to sufficiently high concentrations. Biological filters contain a high-surface-area substrate (media) upon which living bacterial populations grow and oxidize ammonia (the principal waste product of larval prawns) to nitrite and then to nitrate (a nontoxic compound). The biological filter should contain approximately 6% of the volume of the entire culture system, and the rate of water flow through it should be 30–100% of the volume of the entire system per hour. Newly hatched larvae stocked at the highest recommended density (100 per liter) will require the highest flow rates (70–100% of the total water volume per hour).

The sand filter should contain 850-micron sand particles that serve to remove particulate matter from water efficiently before the water flows through the ultraviolet light unit and the biological filter. Removal of particulate matter from the water increases the operational efficiencies of both the ultraviolet light and biological filter. Exposure to ultraviolet light dramatically reduces the concentration of bacteria in the water, including pathogenic bacteria. The sand filter must be flushed (backwashed) once to several times daily, depending upon the size of the larvae (resident biomass in the system) and the amount of food fed. This procedure is designed to prevent accumulation of particulate organic material that can clog or cause channeling of water flow, which would reduce the filtering efficiency. Other types of systems designed for the removal of particulate material from water in recirculating systems are available. Daniels et al. (1992) have provided details concerning requirements for materials and equipment based upon a specific production goal.
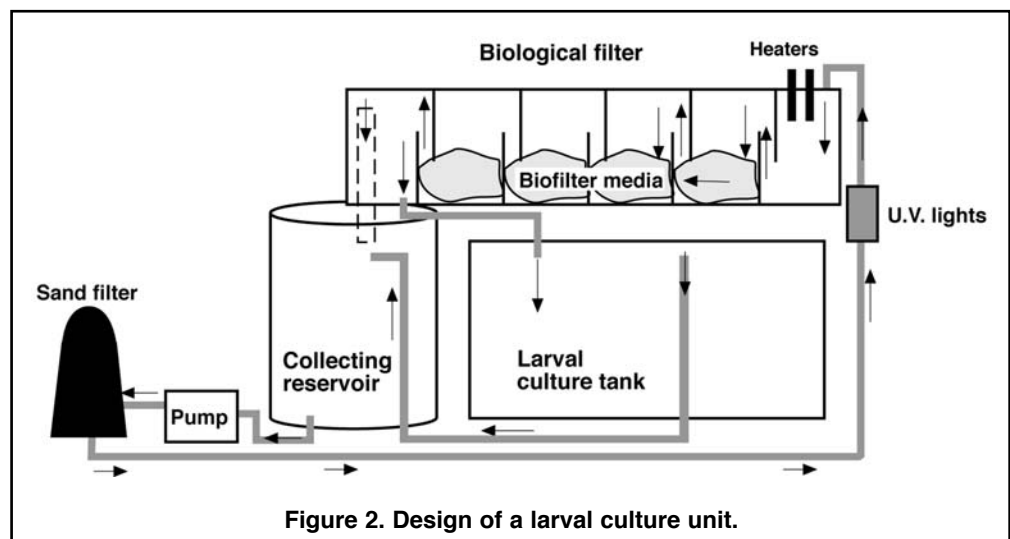

Figure 2. Design of a larval culture unit.

Clean, sterilize, and flush the larval culture system before adding water. Water used for the initial filling should pass through a 5-micron bag filter. After the system is filled and operational, add a chlorine-based sterilizing agent to achieve a chlorine concentration of 5 mg/L (parts per million [ppm]). If you perform this sterilization procedure several days before stocking newly hatched larvae, then no dechlorinating agents (i.e., sodium thiosulfate) are required. This protocol is recommended because the presence of dechlorinating agents has been implicated in causing mortality of prawn larvae. If only freshwater or slightly saline water is available, then you must add a commercially produced salt mixture and thoroughly mix it with the freshwater to achieve the appropriate salinity for culture. Always use high-quality marine salt mixtures of proven effectiveness because inferior salt mixtures can adversely affect growth and even cause mortality.

Preparation and Maintenance of Biological Filter Media

The water volume of the biological filter should be at least 6% of the total volume of the culture tanks that it serves. A variety of materials can serve as biofilter media (surface material). However, the media must provide a large surface area for the growth of bacterial populations. Either all or a portion of the biological media should be calcareous material such as small crushed oyster shell or coral. Storage and handling of media are facilitated when it is contained in bags fashioned from fiberglass window screen.

Media destined for use in the biological filter are activated in a separate preconditioning container by introducing other media that already have established and growing populations of nitrifying bacteria. Once appropriately conditioned, selected quantities of the biofilter media are transferred to the actual biological filter unit as needed (i.e., as the biomass of the larvae and their corresponding rate of ammonia production in the culture tank(s) increase). Temperature (28–30 °C [82.4–86 °F]) and salinity (12 g/L [ppt]), should be the same in both the activating and the culture tanks. Constant, vigorous aeration must be supplied to the activating tank. Following is the procedure for activation of media for use in a biological filter, adopted from Daniels et al. (1992):

(1) Calculate the expected daily maximum load of ammonia-nitrogen in the larval culture system based on the anticipated number of postlarvae to be pro-

duced in the entire larval system. Based on empirical data, the maximum rate of production of ammonia-nitrogen (ammonia-N) by a larva of *M. rosenbergii* in a closed, recirculating culture system is approximately 30 μg per day (1.05×10^{-6} oz per day). For example, if the maximum expected amount of ammonia-N produced by 2 million larvae within the system in a 24-hour period is 60 g (2.12 oz), then 226.8 g (8 oz) of ammonium chloride need to be oxidized completely by the biofilter media being "activated" in the preconditioning tank. This determination is based upon that fact that 1 g (0.035 oz) of ammonium nitrogen exists in 3.78 g (0.133 oz) of ammonium chloride. A bag of crushed coral weighing 2.26 kg (4.98 lb) usually serves as substrate for a population of nitrifying bacteria that is capable of nitrifying (oxidizing) 1 g (0.035 oz) of ammonium chloride in 24 hours. Therefore, 227 bags of crushed coral would be needed to nitrify 60 g (2.11 oz) of ammonia-N. The maximum volume of coral media, representing less than 4% of the total rearing volume, is generally reached by the 17th day of a culture period or when the larval stage index of the population is 8.5 (Griessinger et al. 1989).

(2) Initially, add 10% of the total required ammonium chloride (NH_4Cl) or another inorganic source of ammonia to the water containing the media.

(3) After a few days, check the levels of total ammonia-N and nitrite-nitrogen (nitrite-N). Low-range ammonia (0.0–0.8 mg/L [ppm] ammonia-N) and nitrite (0.0–0.2 mg/L [ppm] nitrite-N) test kits for salt water are satisfactory for such determinations. If both levels are below detection, then add the same amount of ammonium chloride recommended in step 2. If, however, either total ammonia or nitrite is still detected, do not add any additional ammonium chloride and recheck levels after 24 hours.

(4) Continue to add the recommended amount of ammonium chloride (see step 2) and check the levels of ammonia-N and nitrite-N. When this amount of ammonium chloride is completely nitrified within 24 hours, double the amount, and follow the previously stated procedure.

(5) As each increasing level of the introduced source of ammonia is consumed within the desired 24-hour period, double the amount of ammonia added as ammonium chloride until the maximum required load is consumed daily (i.e., within 24 hours).

Generally, 2.26 kg (4.98 lb) of crushed coral media containing a satisfactory population of nitrifying bacteria will nitrify (oxidize) 1 g (0.035 oz) of ammonium chloride in 24 hours.

(6) After oxidation of the maximum level of ammonia is achieved within 24 hours, the larval culture cycle can begin. As needed, the proper amount of media is sequentially removed from the preconditioning tank and placed into the biological filter. Media that remain in the preconditioning tank must still be maintained at their maximum level of ammonia and nitrite consumption. The amount of ammonia that needs to be added for maintenance will decrease as the amount of media in the preconditioning tank decreases.

Feeds and Feeding

No nutritionally complete, formulated diet is currently available to achieve consistently successful larval culture of *M. rosenbergii*. Therefore, live food is required. Newly hatched nauplii of *Artemia* (brine shrimp) have been the overwhelming choice for use as a nutritionally complete diet. *Artemia* are available as cysts (dormant unhatched eggs) from a variety of commercial sources. Newly hatched *Artemia* with an undigested yolk sac are an excellent source of nutrition. After the cysts have been sterilized and fully or partially decapsulated, they should be hatched under clean conditions to prevent newly hatched nauplii from being a potential source of disease organisms when added to the larval culture tank. A suggested procedure to produce live *Artemia* nauplii for feeding follows:

(1) Cyst hydration — Cysts are hydrated by immersion in fresh or seawater (less than 35 g/L [ppt]) at 25°C (77°F) for 1 hour.

(2) Sterilization and decapsulation — Cysts are then sterilized and decapsulated through the addition of 1 g of commercial calcium hypochlorite (HTH) per liter of hydration water. Cysts should be kept in this sterilizing bath for 20 minutes. During the decapsulation process, the cysts should be kept away from direct sunlight.

(3) Washing and deactivation — Cysts are separated from the bath by pouring the mixture through a 120-micron (0.0047-inch) screen. Cysts that are collected on the screen are then thoroughly washed with freshwater or seawater until the odor of chlo-

rine is no longer detected. Toxic chlorine residues that may adsorb to the decapsulated cysts can be deactivated by two dips into a 0.1 N hydrochloric acid (HCl) or acetic acid (CH_3COOH) solution as recommended by Bruggeman et al. (1980). The duration of the deactivation should not exceed 30 seconds, and it should be followed by another washing of the cysts.

Hatching of cysts is best achieved in conical-bottom, funnel-shaped, PVC containers that are equipped with a valve at the narrow end. Stock cysts at approximately 1.5 g/L (0.20 oz/gal) in natural or artificial salt solutions having a salinity of 10–12 g/L (ppt). The hatching water can be enriched with 2 g/L (ppt) of sodium bicarbonate ($NaHCO_3$). The pH of the water should remain above 8, and water temperature should be within the range of 25–30 °C (77–86 °F). Provide aeration to ensure that levels of dissolved oxygen are maintained above 2 mg/L (ppm). Illuminate the hatching containers with 60-watt fluorescent light bulbs (1,000 lux) that are located 20 cm (7.87 in) above the water surface. After approximately 24 hours, harvest hatched *Artemia* nauplii according to the following procedure:

(1) Turn off air; remove standpipe (if one is used), heater, and airstones. Then, cover the top of the hatching container with a dark lid or black plastic for 15–20 minutes. Unhatched cysts and shells from hatched cysts will rise to the surface and have a dark brown color. *Artemia* nauplii are bright orange, and most should concentrate within the water column near the bottom of the hatching container.

(2) Slowly drain the water containing the newly hatched nauplii from the bottom of the container through a l20-micron (0.0047-in) mesh screen and stop when the dark brown *Artemia* eggshells begin to appear.

(3) Thoroughly rinse the nauplii collected on the screen with fresh or brackish water.

(4) Nauplii newly hatched from a total of 50 g of cysts can be safely stored in 1 L of seawater held within an insulated container and chilled to not less than 5°C by the addition of ice packs. The reduction in water temperature caused by this procedure reduces the metabolism of the nauplii and the rate of loss of nutrients from the yolk sac, thereby sustaining the highly nutritional value of the food.

Generally, 150,000 *Artemia* nauplii hatch from 1 g of cysts. However, the hatching characteristics (rate, hatchability) of cysts vary according to time, storage conditions, geographical origin, and commercial brand. Exercise caution when purchasing cysts. A comparatively lower purchase price generally indicates lower hatching performance, etc., and the cost-effectiveness of use of this lower quality must be considered. Generally, the poor performance of some batches will not be adequately compensated by a reduced selling price. Most prawn larvae begin feeding 1 day after hatching (larval stage 2). It is better to provide frequent feedings of live food from sunrise to sunset, rather than one or two feedings spread over a long interval of time. Without frequent feedings, the nutritional value of uneaten *Artemia* in the water column decreases over time because the nutrients contained in the yolk sac are continually being removed to satisfy growth and metabolic needs.

Newly hatched, live *Artemia* nauplii retained on a 120-micron-mesh harvest screen are fed to prawn larvae. A suggested daily feeding rate of nauplii according to day poststocking and stage index is presented in Table 1. The initial morning feeding should consist of 40% of the total number of *Artemia* to be fed that day (daily ration), followed by 20% of the ration later in the morning. The remaining 40% of the daily ration is fed during the afternoon. Any excess *Artemia* that remain after the daily ration has been fed should be frozen in cubes within ice cube trays. This procedure is recommended as a safety precaution for use during the morning of the following day if a sufficient amount of live *Artemia* are not available due to a poor hatch, or simply for use as an initial early-morning feeding.

No later than midmorning, collect a sample consisting of 50–100 larvae and examine them under a dissecting microscope to determine whether their guts are full. Full or mostly filled guts indicate healthy individuals. During the entire larval cycle, be careful to monitor routinely whether guts are full. Empty or almost empty guts are an indicator of inferior culture conditions such as poor water quality, high levels of bacteria, or insufficient levels of food provided.

Day of cycle	Stage index	*Artemia* per larva		Supplemental feed		Particle size	Flushing screen
		a.m.	p.m.	Upper	Lower		
		no.	no.	mg	mg	µm	µm
1	1	0	0	-	-	-	
2	1.5	3	3	-	-	-	
3	1.8	3	3	-	-	-	
4	2.2	9	8	-	-	-	
5	2.7	10	9	-	-	-	
6	3.2	12	10	-	-	-	300
7	4.0	16	14	(0.08)	(0.08)	300-500	
8	4.8	22	20	(0.09)	(0.08)		
9	5.4	27	23	(0.11)	(0.11)		
10	5.6	32	28	(0.18)	(0.15)		
11	6.4	38	32	0.3	0.2	500-700	500
12	6.9	42	38	0.38	0.25		
13	7.2	47	43	0.43	0.3		
14	7.9	49	45	0.55	0.4		
15	8.3	51	47	0.65	0.5	700-900	700
16	8.9	53	48	0.75	0.6		
17	9.1	54	51	0.8	0.6		
18	9.6	54	51	1.1	0.6	900-1200	
19	9.8	56	54	1.2	0.75		
20	1st Postlarvae	58	58	1.2	0.8		
21		65	65	1	0.8		
22		58	58	1	0.9		
23		58	58	0.85	0.9		
24		56	56	0.85	0.8		
25		53	53	0.75	0.7		
PL		62	62	0	0.3		

Table 1. Stage-dependent feeding rates for *Artemia* nauplii and for the supplemental diet. Recommended particle size of supplemental diet and the mesh size of the screen for flushing are included.

Supplemental Feed

A supplemental inert diet is usually fed during mid-morning and late afternoon, approximately 7–10 days after a postlarval production cycle begins. The guts of the larvae should be as full of *Artemia* as possible before feeding of the supplemental diet. When supplemental feeding occurs, position a large-mesh screen (150, 400, or 710 microns, depending upon the size of the larvae) around the standpipe of each culture tank to allow for the exit of uneaten or partially eaten *Artemia* and feces from the tank. The ingredient composition of a typical supplemental diet is fish or squid, chicken eggs, beef liver powder, and a marine fish oil that is a good source of highly unsaturated fatty acids (Table 2). A recommended procedure for the preparation of a supplemental diet follows:

(1) Thaw squid or fish at room temperature or in a microwave oven. Clean squid by removing pen, ink sac, skin, eyes, and beak; clean fish by removing scales, skin, and bones. Sterilize the squid or fish by placing it in a microwave oven and cooking it on high for 7–8 minutes per kilogram (3.18 minutes per pound). Homogenize the sterilized fish or squid tissue in a commercial-grade food processor until a well-blended mixture (i.e., smooth texture with no chunks) has been achieved.

(2) Mix chicken eggs, marine fish oil, and beef liver powder together well, and then add this mixture to the squid or fish homogenate within the food processor.

(3) Gradually add an ingredient for binding purposes (e.g., alginate) and continue mixing slowly until a paste eventually forms and then begins to form balls and detaches from the walls of the food processor.

(4) Take the paste and form thin patties manually or with a press. Then place these diet patties into a plastic bucket containing approximately 4–5 g/L (ppt) of calcium chloride ($CaCl_2$). A slightly additional amount of $CaCl_2$ can be added to the water to increase the rate of binding. The outer layer of each patty will begin to harden quickly and eventually develop a rubbery texture. When this change in texture has occurred, press a patty between your hands and then slide your hands in opposite directions to produce a thinner patty. After the patties have been separated and have assumed a rubbery texture, they

Table 2. Ingredient composition of supplemental diet.

Ingredients	Percent wet weight
Squid, cleaned	85
Cod liver oil	2
Eggs	10
Beef liver powder	3

are processed in a food mill. As larvae increase in size during the production cycle, replace the food mill with a 1.6-mm (l/16-in) cheese grater to produce larger particles of the diet. Create smaller particles by manually pushing the material through sieves to obtain the desired particle sizes. Suggested mesh sizes are 250-micron (0.009-in), 425-micron (0.017-in), 600-micron (0.024-in), 850-micron (0.033-in), and 1,000-micron (0.039-in). The resulting sieved diet should be rinsed thoroughly to remove fine particles that can foul the water and contribute to unwanted bacterial growth within the culture tank. Drain the feed before storing either refrigerated (several days) or frozen. The size of particle fed depends on the size of larvae; it normally ranges from 250–1,000 microns (0.012–0.039 in) (Aquacop 1977).

Separation of Larvae and Postlarvae

After metamorphosis through the 11 larval stages has been completed, larvae then metamorphose into postlarvae. After a significant proportion of larvae (25–33%) has transformed to postlarvae, transfer the remaining larvae to another culture tank so that the postlarvae can be collected for transfer to the nursery phase of culture. The relocated larvae will eventually transform to postlarvae. Generally, two transfers of larvae are required per production cycle. Separate larvae from postlarvae during mid- to late morning after postlarvae have eaten and are clinging to the wall of the culture tank, while larvae are localized in a feeding ring away from the wall of the tank. Collect larvae from these areas of concentration with a small-mesh net and move them to another tank. Be careful to ensure that water quality in the transfer tank is the same as that in the culture tank. In round cylindrical tanks, larvae and postlarvae can be effectively separated by creating a vortex of water at the center of the tanks through the use of paddles. Free-swimming larvae are concentrated within the water column at the center of the tank while postlarvae cling to the sides and bottom of the tank.

After transferring the larvae, transport one-half to two-thirds of the water in the tank where the postlarvae remain to another holding tank and sterilize this water for future use. The postlarvae are now ready for acclimation to freshwater. Freshwater should be added gradually, so that salinity eventually decreases to 0 ppt within a 24- to 36-hour period. At the end of this period, determine the mean weight of individual postlarvae by weighing a bulk sample of a known number of postlarvae. This procedure will provide an estimate of the number of postlarvae produced per production cycle. The desired number of postlarvae to be stocked into each tank (density) used in the nursery phase can be accurately monitored by dividing the total biomass (weight) of groups of postlarvae to be stocked by the mean individual weight. Generally, survival at termination of the hatchery phase of culture ranges from 40–80%.

Nursery

The nursery stage of culture is the period when juveniles are produced for stocking into production ponds. This management practice is included for culture of *M. rosenbergii* in temperate climates to increase an otherwise time-restricted growing season due to growth-limiting and lethal water temperatures in production ponds. A by-product of this management approach is a larger animal for stocking into growout ponds, which reduces the potential for poststocking mortality due to stress or predation by insects.

Nursery culture is generally conducted in tanks within climate-controlled buildings. Water temperatures should range from 25–28 °C (78.8–82.4 °F). The design of a nursery facility will vary according to the respective need for insulation to maintain desired water temperature. In some regions, heated greenhouses may be sufficient, but other locations will require heated buildings that are insulated. The costs of maintaining the desired optimal water temperatures for growth during the nursery phase are important components in the assessment of the economic feasibility of this phase. In most locations, immersion heaters will also be required to maintain water temperature. To conserve water and heat, water recirculation systems are recommended. Flow-through systems equipped with heaters may also be used, but practicality is dependent on availability, temperature, and cost of the water. The use of recirculating systems will require the activation and maintenance of populations of nitrifying bacteria (biological filters) to transform toxic ammonia to nontoxic nitrate. Development, use, and maintenance of biological filters are described in the hatchery section of this bulletin, and the same procedures described for brackish water systems are applicable to freshwater systems. No pesticides should be used in or near (at least 100 yd) a nursery facility.

The depth of nursery tanks/raceways for culture generally should not exceed 1.2 m (4 ft) to provide for easy maintenance. Tanks constructed of a variety of plastics and aboveground swimming pools with a liner of at least 0.1 mm thickness are suitable. Distribute artificial habitat (substrate) throughout the water column to increase the available surface area to permit prawns to distribute themselves in three dimensions within the tank. As a result of this separation, the frequency of aggressive encounters and the opportunity for cannibalism are reduced. The products of this management practice are an increase in survival as well as a potential increase in the amount of energy allocated to growth. Include substrate at a level that increases the available surface area of the bottom and sides of the tanks by approximately 50%. An amount that exceeds 100% of the surface area does not provide any additional benefit. If a flat material is used, then both sides should be included in the calculation of the amount of substrate required. During the period of the nursery phase, the required amount of substrate can be added gradually as juvenile prawns become larger and more aggressive. Growth or survival does not appear to be affected by whether the substrate is oriented horizontally or vertically in the water column (Wilson et al. 2002).

The stocking density for nursery tanks should range from 3–6 postlarvae per liter of water (12–23 postlarvae per gallon). Stocking density can also be based upon the amount of substrate present in the nursery tank — 215–430 postlarvae per square meter (20–40 per square foot) of surface area of substrate (Taylor et al. 2002). This recommended stocking density based upon surface area of substrate is similar to that based on water volume when the amount of substrate is equivalent to 50% of the combined surface area of the bottom and sides of a culture tank. The addition of substrate is critical. A 25% increase in survival was realized after 60 days of nursery culture when substrate was provided (Taylor et al. 2002).
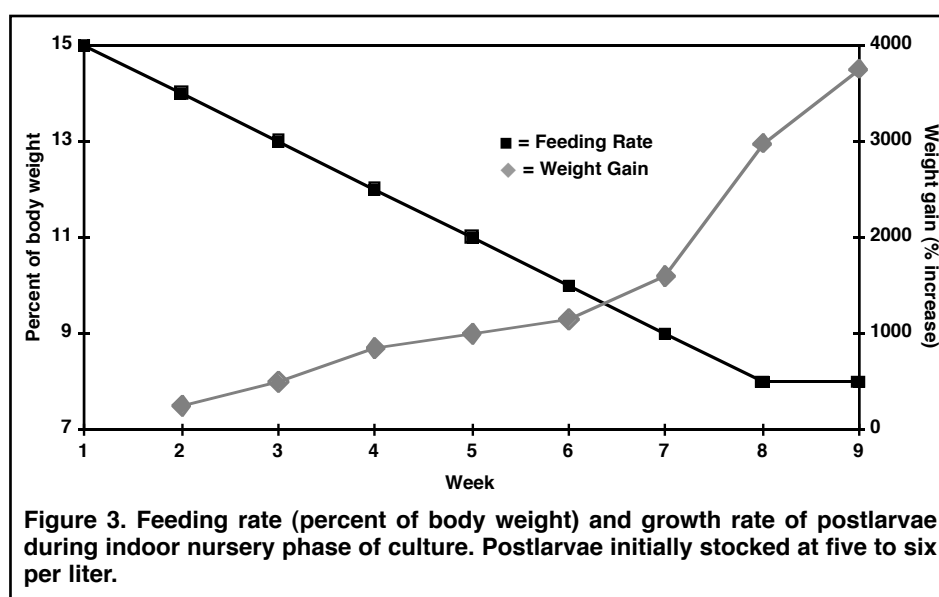
The suggested initial stocking density is based upon achieving good survival and a suitable stocking size within an economically practical amount of time. Typically, a nursery phase of 40–60 days results in a population of juvenile prawns with a mean weight of 0.1–0.3 g, individual weights

that range from 0.4–0.8 g each, and survival that ranges from 55–80%. Survival varies according to stocking density, amount of substrate used, feeding rate, water quality, duration of the phase, and numerous other variables. Under the density and associated conditions prescribed, survival can be reasonably estimated by assuming 1.5% mortality per week for the first 4 weeks, 3% mortality per week for the next 5 weeks, and up to 3% per day for the size of juveniles attained after 9 weeks.

Figure 3. Feeding rate (percent of body weight) and growth rate of postlarvae during indoor nursery phase of culture. Postlarvae initially stocked at five to six per liter.

During the nursery phase of culture, the biomass of a population of juvenile prawns in a tank reaches a sufficiently high level whereby the juvenile prawns respond by a reduction in growth rate. This density-dependent growth response has been shown to begin when a biomass density of 0.5 g/L is achieved (D'Abramo et al. 2000). At a density of 5 juveniles per liter, this density is achieved when the mean weight of the population is 0.1 g (100 mg). Therefore, under the prescribed stocking densities and other management protocol for nursery culture, growth rates are likely less than optimal after the first 35 days of a 60-day nursery phase. However, despite this density-dependent reduction in growth rate, the suggested densities are still designed to provide for a cost-effective enterprise.

Prawns in the nursery phase should be fed a high-protein (approximately 55% crude protein, dry weight) trout or salmon starter diet (#1 then switch to #2 particle size). Commercial diets manufactured by Zeigler Brothers, Inc., (www.zeiglerfeed.com) or Rangen, Inc., (www.rangen.com) have been used successfully. During the nursery stage of culture, the particle size of diets fed should not exceed #4. A feeding schedule based on percent of live body weight and an empirically derived growth curve for *M. rosenbergii* during the nursery phase of culture is provided in Figure 3. Divide the total daily ration into at least two separate morning and afternoon feedings. To avoid poor water quality caused by overfeeding, adjust the amount of daily ration based upon the observed consumption of food.

Three times per week, feed prawns a dietary supplement consisting of shredded frozen beef liver at a rate equivalent (on dry weight basis; liver moisture content is approximately 80%) to the daily ration of formulated feed. The liver diet is best prepared by shredding it from a frozen form manually with a cheese grater. By following this procedure, the liver particles can be either rinsed or slowly introduced directly to a tank so that uneaten particles do not accumulate on the substrate or bottom of a tank. To avoid a potentially rapid deterioration of water quality, divide feeding of the total shredded beef liver ration into equivalent amounts over at least three separate times during the day. Despite this precaution, feeding beef liver in recirculating systems can somewhat compromise water quality and partial water exchanges may be necessary.

Before stocking nursery tanks, calculating feeding rates, stocking ponds, or selling juvenile prawns, you must first estimate weight. A relatively accurate estimate of a mean individual weight can be achieved by collecting several samples of at least 100 prawns, spinning them in a net to remove excess water, and then weighing them. Survival of prawns is not adversely affected by the spinning procedure. The calculated mean individual weight can then be multiplied by the number of the prawns desired, and this total weight can be used to guide in the collection of the actual number of prawns required. Samples are often disproportionately composed of smaller prawns that are easier to collect. As a result, calculation of the mean individual weight for the population is often an underestimate, leading to an overestimate of the number of juveniles. This is a fundamental problem in obtaining an accurate determination of the amount of juveniles for sale to producers, and survival at the termination of the nursery phase of culture.

Size Grading of Nursery Populations

Size grading of juveniles from a nursery-grown population before stocking into production ponds is an effective method to increase mean individual weight and total yield at harvest. Size grading is a simple stock manipulation procedure commonly practiced in the husbandry of terrestrial animals. Grading separates the larger, fast-growing prawns from the smaller, slow-growing ones, a size disparity that is the product of the typical social hierarchy that develops among males during the nursery phase. When these separated populations are independently transferred to production ponds, growth of the smaller males is no longer negatively impacted by the presence of the larger, faster-growing males. After stocking into production ponds, the growth rates of smaller males commonly increase to compensate for the comparatively slower growth rates that occurred during the nursery phase (compensatory growth). The division of nursery-raised populations by size results in a dramatic reduction in the proportion of small males that is generally characteristic of prawn populations harvested from production ponds stocked with ungraded juveniles. The reduction in the number of small males at harvest increases total yield and potential revenue. The weighted production from ponds separately stocked with each of two populations obtained by grading can be 25–30% greater than production in ponds stocked with the same group of prawns that were not graded. However, recent research results suggest that these increases in production are not achieved when size-graded populations are stocked at a low density of 21,000 prawns per hectare (8,500 per acre).

Size grading can be performed with either bar graders that are conventionally used to grade small fish or a derivation of the bar grader design. The type of numerical separation by size achieved will depend upon the bar width used and the weight (size) distribution of the population of nursery-raised prawns. Experience has demonstrated that a good relationship exists between bar width and the mean weight of the largest prawns that pass through the bars in a vertical plane. A prawn size (weight)-bar width relationship should be determined for the specific size-grading technique used. A 50%-50% (upper-lower) or 40%-60% (upper-lower) numerical separation is advised so that comparable numbers of juvenile prawns representing each graded population are available for stocking. Be careful to avoid a situation where the result of the grad-ing is a disproportionate number of prawns in one size class (i.e., 80%). Stocking of populations arising from a 70%-30% (upper-lower) separation has still produced substantial increases in overall production relative to that of ungraded populations that were stocked.

No specific grading procedure is recommended. Juveniles move toward a flow of water, and this behavior may assist in the use of passive grading techniques. Other, more active grading techniques would involve the movement of a grader through a population or the forced movement of a population through a stationary grader. The choice of technique should be based upon the experience, ease, effectiveness, and resources available to the culturist. Always conduct size grading with the provision of plentiful aeration to avoid stressful conditions.

Transport of Postlarvae and Juveniles

Two methods are commonly used for shipping freshwater prawn postlarvae and juveniles. The first method of shipment is identical to that used for many years for live shipment in the ornamental fish trade. Either postlarval or small juvenile prawns are placed into a plastic bag containing water and pure oxygen; the bag is placed in a cardboard box with a Styrofoam liner. This method is used for either airfreight or short-distance ground delivery. The second method of transport is live haul and requires a tank/container with well-aerated (oxygen, or forced air) water. Agitators should not be used to aerate the water because they will injure or kill postlarval prawns. Live-haul containers may or may not be insulated. Live haul is a much more economical approach to transport comparatively large numbers of postlarvae and juveniles that need to be shipped long distances. Live haul is also the only cost-effective method for transport of nursed juveniles that are 30 days and older.

Some practices for successful shipment are common to both methods. Prawns need to be acclimated slowly to the conditions (temperature, salinity, pH, etc.) of the shipping water. Water for shipping is usually cooled to within a range of 18–22 °C (64–72 °F) to reduce the level of activity and metabolism of the prawns — specifically oxygen consumption and ammonia excretion. Shipping temperature should be based upon the anticipated ambient temperature conditions during the time interval between shipment and receipt. The air temperature of vehicles, airline cargo holds, and loading docks en route, combined with duration of exposure, will influence water temperature at the final

destination. Prawns should not be fed for at least 12 hours before shipping. Lack of food will reduce the rate of production of ammonia, a toxic excretory product of protein metabolism. Periodically, determine the mean individual weights of groups of prawns throughout the procedure of loading for shipment. This ongoing determination of mean weight of the population ensures greater accuracy in the provision of the desired numbers for shipment. Those prawns first removed (captured) by net from a culture tank are typically the smallest.

When shipping prawns, it is very important to consider density and weight (biomass). Generally, 5,000 new postlarvae are shipped in 2.5-gal (9.5-L) aquarium trade shipping bags. Each postlarva weighs approximately 0.01 g, so the weight (biomass) density is 20 g/gal (5 g/L). If larger nursed juveniles are to be shipped in these shipping bags, then stocking densities must be reduced significantly. Nursed juveniles that weigh approximately 0.1 g each — a tenfold increase in weight over a newly metamorphosed postlarva — should be stocked at a density of 750 per 2.5-gal bag (30 g/gal or approximately 7.5 g/L). The weight per gallon (or liter) shipped increases by 50% for larger prawns; however, density decreases by 85%. A study conducted by Coyle et al. (2001) using sealed bags with pure oxygen, box containers, and juvenile prawns of 0.26 g ± 0.02 g indi-cated that transport at 25 g/L resulted in lowest cost per individual prawn. Water quality and survival data indicate that stocking densities greater than 10 g/L and durations exceeding 8 hours in sealed containers may result in a deterioration of water quality and stressful conditions for transported prawns.

Tanks/containers used for live transport can vary in size, shape, insulation value, and aeration capacities. Recommended biomass densities (grams per liter) for live haul and boxed shipping are similar. Live haul capacities for juveniles of approximately 0.3–0.4 g each are approximately 33 g/gal (8.75 g/L). Therefore, you would ship approximately 65–70 juveniles per gallon at this stage of development. Larger juveniles need to be shipped at lower densities. Density can be increased slightly for live haul trips that are less than 2 hours. A water salinity of 1 ppt is commonly used for live hauls. Salinities of 4–5 ppt would likely be beneficial, and the cost for the additional salts would be included in the transport cost. As expected, lower stocking densities yield higher survival, especially on longer trips with larger prawns. Live-haul shipments with lower-than-recommended-biomass densities will most likely ensure higher postshipping survival, but this benefit must be weighed against the cost of transport per individual juvenile.

Growout

Postlarvae or juveniles for the pond growout phase can be purchased through commercial hatcheries currently located in several states, including Mississippi, Texas, Florida, Kentucky, and Tennessee. Stocking of juveniles is recommended to reduce poststocking mortality and control size variation at harvest. The price varies according to age (size) and quantity desired but is approximately $20–30 per 1,000 postlarvae and $60–85 per 1,000 juveniles.

Pond Design and Preparation

Production ponds for freshwater prawns should have many of the basic features of ponds used for the culture of channel catfish. A good supply of fresh water and soil with excellent water-retention qualities are essential. Well water is the preferred water source for raising freshwater prawns. Collected runoff from a surrounding watershed or runoff from rivers, streams, and reservoirs can be used. However, the quality of the water may be subject to adverse changes, and sufficient quantity (availability) for needs is unpredictable.

Whatever the source, the quality of water must be evaluated for its suitability for culture before a site is selected. Some water quality characteristics considered absolutely necessary for good prawn growth include at least 90 days of water temperatures greater than 20°C (68°F), pH that ranges from 7.0–8.5, and a water hardness that ranges from 15–300 mg/L (ppm). Ponds should not be constructed in areas that are subject to periodic flooding. Before stream or river water enters into ponds, it should be passed through a nitex screen with a mesh diameter that does not exceed 300 microns. This procedure should prevent the undesired introduction of fish and fish eggs into the pond.

Analysis of soils for the presence of pesticides is another procedure that is essential before selection of a site. Many pesticides applied in the management of row-crop farming are toxic to prawns. Therefore, ponds should not be constructed in contaminated soils, in areas that are subject to drift from agricultural sprays, or in areas exposed to runoff water that may be susceptible to pesticide contamination. Samples from water

sources intended for use in culture should also be screened for pesticide contamination.

Local or regional offices of the Soil Conservation Service can provide assistance in pond design and layout. The surface area of growout ponds should ideally range from 0.4–2.0 ha (1–5 A). Successful production in larger ponds has been achieved, but the logistics of management and harvest present some problems. Ideally, the shape of the pond should be rectangular, thereby providing the opportunity to distribute feed across the entire surface area of water. The bottom of a production pond should be completely smooth and free of any potential obstructions to seining. It should also be free of any deep depressions where prawns will escape capture by seine or become stranded if a drain harvest is performed.

Ideally, ponds should have a minimum depth of 0.6 m (2.15 ft) at the shallow end and slope to a maximum depth of 1.2–1.5 m (3.93–4.10 ft). The slope of the pond bottom should allow for rapid draining and consist of a 4-in drop in elevation for every 100 ft of pond bottom. A smaller slope may contribute to the formation of small depressions on the pond bottom where prawns become stranded during a drain harvest. If a drain harvest is planned, then a slightly deeper (10–15 cm, 4–6 in) area of 4.6–6.1 m (15–20 ft) should be constructed around the drainpipe. During drain harvest, the prawns will concentrate in this area to provide for a practical procedure for removal. Alternatively, if the extent of the drainage fall allows, prawns can be collected in a net or basket placed in water on the outside of the pond levee. If a pond is designed properly and the drainpipe is free of obstructions, this method requires the least amount of labor.

Best results for draining and harvesting ponds with 0.4–1.2 ha (1–3 A) of water surface have been realized with one 35- to 40.5-cm-diameter (14- to 16-in-diameter) drainpipe or two 20- to 25-cm-diameter (8- to 10-in-diameter) drainpipes included in the design. With the flow capacity of these pipes, full draining of most ponds will occur within 24–48 hours. If more pipes or larger pipe diameters are used, then the draining time will correspondingly decrease. Provision of at least two pipes also provides backup if one pipe should become obstructed. Draining of the final 0.9 m (1 ft) of water should be sufficiently slow to allow time for prawns to either collect within the "in-pond" catch basin or pass through the drain for collection outside the levee. One 25-cm-diameter (10-in-diameter) pipe is ideal for draining the final 0.9 m (1 ft) of water. Some prawns

may still have to be removed from the pond bottom as the final water drop may strand some in soft muds.

Collect soil samples at six different locations from the bottom of a newly constructed pond and mix them to make a composite sample. Place each sample in a soil-sample box — available from county offices of the Mississippi State University Extension Service — and send it to the MSU Extension Soil Testing Laboratory or another soil-testing laboratory to determine pH. If the pH of the soil is less than 6.5, perform an application of agricultural limestone to increase the pH to at least 6.5, or preferably 6.8.

Provision of Additional Habitat (Substrate)

Much research has been devoted to the evaluation of the effect of substrate in production ponds (Tidwell et al. 1998, 1999, 2000). Substrate consists of any two- or three-dimensional material that can be added to fill the water column and serve as additional habitat for the prawns. A design that allows easy introduction and removal, as well as a material that will give multiple years of use are recommended. Substrate material that has been commonly used in research investigations is an orange PVC barrier fencing often found along the perimeter of construction sites. This material is UV-protected and has been used for at least 5 consecutive years without deterioration in quality. Other materials such as bird netting or old nets have also been used successfully. Cost and availability are important considerations in minimizing the proportional contribution of this material to overall operational costs.

Substrate should be suspended vertically in the water column, and the surface area of both sides should be equivalent to at least 50% of the bottom surface area of the pond, estimated as being equivalent to the water surface area. Reinforcement bars (rebars) are commonly used to support the vertical substrate within the water column, and one rebar is positioned approximately every 25 ft along the substrate. Provision of habitat has resulted in as much as a 25% increase in total production in experimental ponds. Generally, realized increases are between 10% and 15%. A comparable increase in production has yet to be demonstrated in commercial production ponds containing substrate.

Pond Management

A feeding-fertilization program at or before stocking — similar to that used for catfish fry ponds — is recommended to discourage growth of common prob-

lem weeds such as *Chara* sp and *Najas* sp. After the ponds are filled with water and at least 1–2 weeks before the stocking of the prawns, apply an inorganic fertilizer to shade out the growth of unwanted (nuisance) aquatic plants. A liquid inorganic fertilizer — either 10-34-0 or 13-38-0 — gives the best results and should be applied at a rate of 1.9 L (1/2 gal) per surface acre. To assist in this procedure, inoculate each pond with water from ponds containing already-established blooms of desired microscopic algal species. Do not use inorganic fertilizers to stimulate phytoplankton growth to shade out undesirable aquatic plants that have already appeared. Inorganic fertilizers stimulate growth of both rooted and filamentous ("moss") nuisance plants. Maintaining a proper phytoplankton bloom will facilitate proper feeding and harvest of freshwater shrimp.

Figure 4. (A) Profile of a freshwater shrimp pond with catch basin and optional outside catch basket. (B) Top view of pond with arrows indicating slope fall direction, catch

To stimulate an abundance of natural food organisms for the prawns, perform multiple applications of organic materials such as distillers' dried grains and solubles, cottonseed meal, or sinking catfish feed. Choice of "fertilizer" should be based on cost and local availability. Start the organic fertilization program with a one-time application of cottonseed meal or sinking catfish feed at 200–300 lb/A after a pond has been filled. Continue fertilization with a commercial catfish feed or meal (finely ground or small pellet is best) at a rate of 15–20 lb/A on alternate days until application of formulated feed begins, usually 6–8 weeks poststocking. At stocking densities of 8,000–24,000 per acre, organic fertilization throughout the growout period appears sufficient to sustain natural food populations for achieving maximum growth.

Operating pond depth should range from 3–4 ft during the growout period. Pond depth during the initial stocking and the beginning of the growout period, when water temperatures are generally cooler, could be increased to 4–5 ft to discourage the growth of aquatic rooted plants and filamentous algae.

Prawn production in ponds can be negatively impacted by the presence of fish that are potential predators, as well as competitors for formulated feed and natural food resources. Existing fish populations must be eradicated before stocking prawns. There are two options for fish eradication: (1) completely drain the pond; or (2) apply 3 pt (1.41 L) of 5% emulsifiable rotenone per acre-foot of water. Rotenone is also potentially toxic to prawns. After it is applied, rotenone breaks down at a rate influenced by temperature, light, levels of dissolved oxygen, and alkalinity. Generally, you can stock prawns without concern for rotenone toxicity 2–3 weeks after application.

Stocking of Juveniles

Before stocking, acclimate juveniles to pond conditions by gradually replacing the water where they are being held with water from ponds where they will be stocked. Replace at least 50% of the transport water. The temperature difference between the holding system and the stocking ponds should not exceed 3°C (5.4°F).

To avoid stress and possible mortality caused by low temperature, stock prawns when the early-morning temperature of the pond water is at least 20°C (68°F) for several days. This management guideline should significantly reduce the risk of mortality of juvenile prawns that would occur due to a rapid decrease in water temperature to 15.6°C or less (60°F or less) caused by unanticipated low air temperatures.

Juveniles — preferably those derived from size-graded populations and weighing from 0.1–0.3 g (0.003–0.011 oz) — have been commonly stocked at densities ranging from 24,700–49,400 per hectare
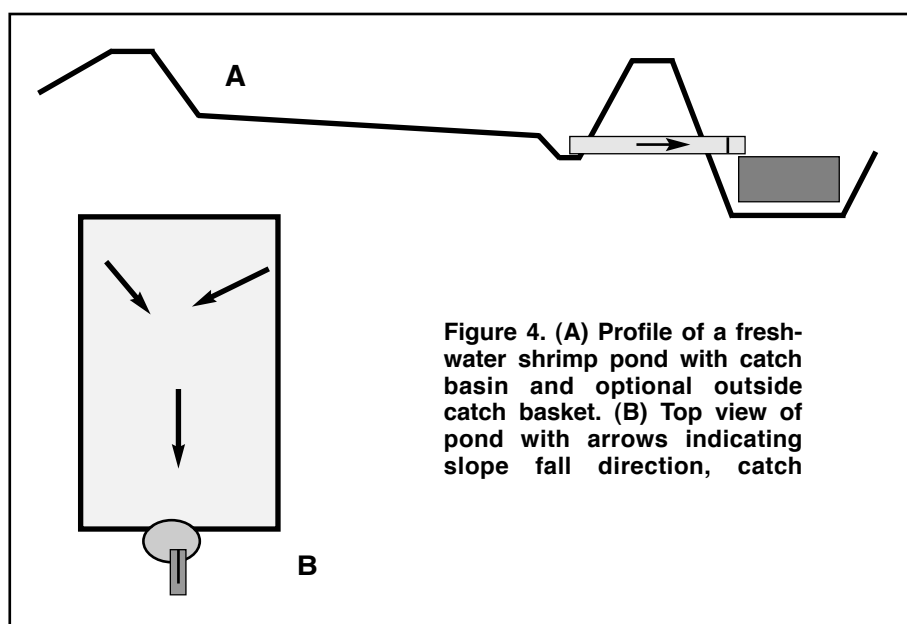
(10,000–20,000 per acre). Lower stocking densities will yield comparatively lower total harvested weight per growout period but higher weight per individual prawn. The duration of the growout period is dependent on the water temperature of the ponds and generally ranges from 120–150 days in central Mississippi. Prawns could be grown year-round — possibly two crops per year — if sufficiently warm water is available.

Feeding

Juvenile prawns stocked into earthen growout ponds at the previously stated densities initially satisfy their nutritional requirements by consuming natural pond biota, such as insect larvae and worms. Researchers have evaluated a variety of feeding practices involving the provision of different nutrient sources at different times during growout. However, for the range of stocking densities previously recommended, commercially available sinking channel catfish feed (32% crude protein) has been determined to be an effective diet throughout the growout phase. Recommended feeding rates are based upon estimated survival, estimated consumption expressed as a percent of live body weight, and the mean weight of the population derived from sampling of ponds (Table 3). Weekly rates based upon density without sampling must be developed eventually for practical use.

A large proportion of the feed is presumed to be not directly consumed by the prawns but rather to serve as a fertilizer (a direct source of nutrients for the populations of natural food organisms). A 1% mortality rate within the pond population is assumed per week, and at the end of the pond growout season, survival generally ranges from 60–85% when proper water quality is maintained through recommended management practices (see water quality management section). Yields typically range from 670–1,350 kg/ha (600–1,200 lb/A). Mean individual weight is inversely related to production and ranges from 28–65 g or 36–15 whole prawns per kilogram (16–7 whole prawns per pound).

Table 3. Weight-dependent feeding rates for semi-intensive pond growout of *Macrobrachium rosenbergii*.	
Mean wet weight	**Daily feeding rate[1]**
<5 g	0%
5-15 g	7%
15-25 g	5%
>25 g	3%
[1]Percent of body weight. As-fed weight of diet/wet biomass of prawns x 100.	

Water Quality Management

Water quality influences the rate of growth of freshwater prawns. Dissolved oxygen is particularly important, and a good oxygen-monitoring program is necessary. Because prawns live on the bottom (in ponds without substrate), levels of dissolved oxygen should be routinely monitored within the bottom 0.3-m (1-ft) depth of water. Oxygen levels at the surface can potentially be lower than those at the bottom.

Electronic oxygen meters are the most reliable and accurate means to determine levels of dissolved oxygen. These meters are comparatively expensive and require careful maintenance and calibration to ensure good operating condition and the collection of accurate data. The need for an electronic oxygen meter increases as the quantity of ponds that need to be managed increases.

If an enterprise consists of only a few ponds, then monitoring of dissolved oxygen levels can be readily accomplished through use of a commercially available chemical oxygen test kit that is generally equipped to conduct 100 independent tests. Water samples for dissolved oxygen analysis can be collected from the lowest foot of the water column with either commercially available or individually fashioned devices.

Dissolved oxygen concentrations should always be maintained above 3 mg/L (ppm). At concentrations below this level, stressful conditions and eventually mortality will occur. Levels of dissolved oxygen that are substantially higher than 3 mg/L (ppm) are recommended because chronically lower levels of dissolved oxygen throughout the growing season can markedly impact yields. Emergency aeration can be achieved by an aerator, a device that increases the rate of transfer of oxygen from air to water. The type and power of the aeration device(s) will be principally determined by the size and shape of the culture pond. Generally, aeration generated by 1 horsepower per surface acre of water is recommended.

During the late-evening and early-morning hours of summer months, when the water temperature of ponds generally exceeds 25°C, dissolved oxygen must be monitored frequently (every 2–3 hours) because rapid decreases in oxygen commonly occur. To assist in predicting whether the level of dissolved oxygen will likely decrease to either stressful or lethal conditions, record the level of dissolved oxygen an hour after sunset and again approximately 2 hours later. Plot these two readings on a piece of graph paper and connect the points with a straight line. By extending the line from

these two points over time, you can estimate the dissolved oxygen concentration before daylight (5–6 a.m.). Use this method cautiously because dissolved oxygen levels do not always decrease at a constant rate. Therefore, late-evening or early-morning dissolved oxygen determinations are strongly advised. Decisions to provide emergency aeration should be based on an anticipated decrease in dissolved oxygen (DO) below 5 ppm. Aeration of ponds for 24 hours each day will reduce the magnitude of diurnal DO fluctuations, but such a management practice may not always prevent DO levels from decreasing to below 3 ppm. Given the design of an aeration device operating 24 hours, continuous water circulation may be a natural by-product. Water circulation may beneficially influence growth, but such a response has not been unequivocally demonstrated in controlled experiments. PTO-driven paddlewheels are recommended for emergency aeration, especially in ponds in the recommended upper range (more than 1 A) of surface area.

Specific information concerning other water quality requirements of freshwater prawns is limited. Although freshwater prawns have been successfully raised in soft water (5–7 mg/L [ppm] total hardness) in South Carolina, the shell is noticeably softer and may be more susceptible to bacterial infection. To avoid this condition, water hardness should range between 50 and 200 mg/L (ppm). In very hard water (i.e., 300 mg/L [ppm] or higher), reduced growth and lime encrustations on the exoskeleton have been observed. Hardness of pond water can be increased through an application of a calcium source such as agricultural gypsum or calcium chloride. The purity of gypsum varies (70–98%) and generally is more readily available than calcium chloride. Assuming 100% purity, an application of 1.72 mg of gypsum per liter of water (ppm) can achieve an increase of 1 mg/L (ppm) in total hardness.

Nitrogenous Compounds

At concentrations of 1.8 mg/L (ppm), nitrite has been associated with mortality in hatcheries, but no definitive information derived either experientially or experimentally about the toxicity of nitrite to prawns grown in ponds is available. During the pond growout phase, high nitrite concentrations in ponds would not be anticipated given the level of prawn biomass associated with the recommended stocking densities and feeding rates. Levels of un-ionized ammonia that exceed 0.1 mg/L (ppm) can adversely affect the growth and health of fish in ponds. At concentrations of un-ionized ammonia as low as 0.26 mg/L (ppm) at a pH of 6.83, 50% of the prawns in the population died within 144 hours (Armstrong et al. 1978). Therefore, concentrations of un-ionized ammonia that exceed 0.1 mg/L (ppm) must be avoided.

pH Requirements

A high pH can cause mortality directly by creating a pH imbalance relative to the prawn tissue. It can also cause mortality indirectly by causing a larger proportion of ammonia to exist in the toxic un-ionized form. Although freshwater prawns have been successfully raised in ponds where a pH has ranged from 6.0–10.0, a pH that remains within the 6.5–9.5 range is recommended. High pH values usually occur in water having a total alkalinity of 0.5–50 mg/L (ppm), often stimulated by the existence of a dense algal bloom. Adding lime to the bottom soil of ponds that are constructed in acid soils can help to minimize severe and possibly lethal fluctuations of pH that might occur during growout.

One management practice that has been implemented to mitigate rising pH in smaller ponds is periodic flushing (removing) of the top 30.5 cm (12 in) of surface water to reduce the quantity of photosynthetic algae in the pond. However, this procedure is not a practical solution in large ponds, and the quality of the effluent (water discharged) may not meet standards established by state or federal agencies. Another management approach to avoid high pH is to spread organic matter, such as corn grain or rice bran, over the surface area of the pond. The organic matter should be introduced gradually, over a period of 2 weeks, to achieve eventually a level of 13 kg/A (32 kg/ha). The decomposition of the organic material releases carbon dioxide that helps to reduce pH. Careful monitoring of oxygen levels must accompany this management procedure. Oxygen levels would tend to decrease substantially due to the heavy oxygen demand arising from the decomposition of the organic material.

Despite following the recommendations for preparing a pond for stocking, a dense growth of filamentous algae may still occur in production ponds. Feeding and seining cannot be performed effectively under these conditions. Introducing low densities of herbivorous fish shortly after stocking the prawns could be an additional precautionary management approach.

Certain aquatic herbicides, particularly Aquathol K and Hydrothol 191, at recommended rates of application have successfully controlled algae growth without hav-

ing any adverse effect on survival or behavior of shrimp. Bioassays to determine survival responses to a variety of herbicides are needed. Before any herbicide is applied, always conduct a simple bioassay. Select healthy juvenile prawns and place them in several plastic buckets filled with aerated pond water containing either no algicide or algicide at the recommended application rate. After 24 hours, if prawns exposed to algicide exhibit mortality or unusual behavior suggesting stressful conditions, then the algicide should not be used.

DISEASES

Unlike marine shrimp, disease has yet to be identified as a major problem affecting production of freshwater prawns. This attractive characteristic is probably due to the comparatively lower amounts of total biomass in production ponds relative to marine shrimp enterprises. However, as stocking rate and biomass per unit area increase, the potential for disease-related mortality correspondingly increases. Some prawns in a pond population may be afflicted with shell disease that is bacterial in origin and clinically manifested by black spots on the outer shell (exoskeleton). Incidence is usually associated with physical damage to the shell. However, the disease is not lethal and is eliminated by the shedding of the old shell and the production of a new uninfected shell. At times, algae or insect eggs may be found adhered to the shell. This condition is neither disease- nor stress-related but would adversely affect consumer acceptance. Maintaining the best possible conditions for growth will encourage molting so that this condition is minimized or eliminated. Disease problems are most prevalent during the hatchery phase of culture and generally result from the proliferation of bacteria caused by an undesirably high organic load. Addition of oxolinic acid at 1 mg/L (1 ppm) is the recommended therapeutic treatment.

HARVESTING

Growout of freshwater prawns in temperate climates involves stocking seed (juveniles) followed by a period of 110–140 days of growth, depending on geographical location. Pond harvest should be completed before morning water temperatures reach 15.6°C (60°F). Prawns can tolerate water temperatures to at least 12.8–14.4 °C (55–58 °F) if the temperature decreases gradually over several days. When pond water temperatures below 68°F occur for a considerable part of a 24-hour period, prawn growth rates are so low that keeping them in ponds for any extended period will not increase production appreciably.

At the end of the growout season, prawns may be either seine or drain harvested. For seine harvest, pond depth (or water volume) should be decreased by one-third before seining. Prawns can be held in small mesh livecars and loaded with a crane-basket onto trucks. Those that remain after seining can be harvested by draining the pond to concentrate them in a large rectangular bar pit (ditch) that is deeper than the surrounding pond bottom. Prawns then concentrate there for seine harvest. Water in the ditch needs to be well aerated. Some prawns may not collect in the ditch after draining and will have to be removed from the pond bottom manually.

Harvest by complete drain-down is labor saving and more efficient. It can be readily and effectively accomplished if ponds are properly designed with a smooth bottom and a slope that will ensure rapid and complete draining. Highly effective harvests have been achieved with properly constructed ponds because prawns living at water temperatures higher than 68°F will follow the receding water and eventually travel through a drain pipe into a collecting device or small collecting pond, generally located on the outside of the pond levee. There, sufficient aeration should be provided to the water to avoid stress and possible mortality as harvested prawns become concentrated. Adequate pond bottom slope and rapid drainage are critical to the efficient harvest of freshwater prawns. Ponds with very flat bottoms and small drains create many logistical problems relative to harvest.

Freshwater prawns are very hardy animals and do not die or diminish in quality when exposed to sunlight and soft muds for a short period of time. They can be collected in buckets or baskets and rinsed with clean water with few losses as long as they are not packed in extremely dense groups and not exposed to warm air temperatures for more than 15–20 minutes.

Whenever possible, aeration devices for maintaining proper levels of dissolved oxygen should be located at the deep end of the pond adjacent to the drain basin area to minimize the accumulation of sediment there. Otherwise, aerators placed at the shallow end of a pond may produce depressions that will strand prawns as they follow the receding water during the drain harvest of a pond.

Selective harvest of large prawns by seining during a period of 4–6 weeks before final harvest has been practiced with the intent of increasing total yield from a pond during a growing season. Selection of the mesh size of the seine (1–2 in) will depend on the desired harvest size of the prawn. Selective harvest may also be accomplished with properly designed traps. Prawns have been trapped using a wide array of traps traditionally designed for the harvest of crayfish. The reduction in population density caused by a partial seine or trap harvest results in an increase in the growth rate of the smaller prawns that remain. Through selective harvest, a freshly harvested product is available over a longer period of time. Insufficient research has been performed to determine conclusively whether a selective harvest practice is cost-effective relative to a traditional, single bulk harvest at the conclusion of the growing season.

LATITUDINAL DIFFERENCES

Other research (Tidwell et al. 1996) has shown that under exact management practices and growing seasons of comparable duration (110–140 days), mean individual harvest weight of prawns and total production have the potential to be greater at higher latitudes in the northern hemisphere. Within the confines of sufficiently long growout periods, this phenomenon appears to be the result of lower mean water temperatures during the growing season. A comparison of the composition of the harvested populations at different latitudes suggests that the prolonged cooler water delays development of the ovary and egg production in female prawns. Since sexual maturity of females is delayed until later in the growing season, energy that would have been spent on reproduction is transferred to growth. As a result, larger females are produced despite the shorter growing season at higher latitudes.

PROCESSING AND MARKETING

Production goals and harvesting practices should be developed in response to the market. Without this approach, financial loss due to lack of adequate storage (holding) facilities or price variability is inevitable. Demand suggests that there are small but lucrative niche markets for large live prawns and heads-on prawns on ice. Other forms will probably have to enter and be competitive within the marine shrimp commodity market. Year-round distribution of this seasonal product will require freezing. An individually quick frozen (IQF) product — both whole and headless — is an attractive form for supermarkets or restaurants. Block frozen is also an alternative method of processing for long-term distribution. Recent studies show that whole prawns, harvested 2–4 hours before exposure to the IQF process, have a shelf life of at least 1 year when stored at -18°C (0.4°F). Cold-water immersion can be used to thaw frozen prawns for immediate use. Any other thawing is restricted to refrigerated conditions. Overall acceptability is maintained for frozen prawns allowed to thaw for up to 24 hours under these conditions (Silva and Handumrongkul 1998).

Recent research conducted at the Mississippi Agricultural and Forestry Experiment Station suggests that adult freshwater prawns can be successfully live-hauled for at least 24 hours at a density of 0.060 kg/L (0.5 lb/gal) with little mortality and no observed effect on exterior quality of the product. Transport under these conditions requires the provision of oxygen to the water. The prawns should be distributed vertically, as homogeneously as possible, throughout the water column, possibly in stacked "shelves." This approach avoids potential mortality due to stress and localized deterioration of water quality from crowding on the bottom of the transport tank. Ideally, the temperature of transport water should be 20–22 °C (68–71.6 °F) to reduce the activity level of the prawns, thus minimizing the incidence of injury and water quality problems, particularly ammonia accumulation. Researchers are investigating an alternative method for overnight transport of live freshwater prawns using a minimal amount of water.

The evaluation of the economic feasibility of pond growout of freshwater prawn in temperate climates of the United States was based upon a hypothetical commercial pond production system (CPPS) using experimental and commercial results derived from the practice of current pond growout technology in Mississippi. Costs and returns of CPPS were estimates based on recommended management practices, biological knowledge of the species, estimated input usage and prices, and established ex-vessel shrimp prices. The CPPS was then evaluated under different combinations of economic and biological scenarios. The economic model used in this analysis incorporated production characteristics from experimental ponds and commercial operations. The model estimated ownership costs of a hypothetical commercial farm.

Experimental production results indicated that 12-count, heads-on prawns could be produced at 1,345 kg/ha (1,200 lb/A) in 0.1-ha and 0.06-ha (0.25-A and 0.15-A) ponds stocked with 30-day-old juveniles at a density of 49,420 per hectare (20,000 per acre). Commercial prawn enterprises have produced yields of 897 kg/ha (800 lb/A) when 0.8-ha to 1.2-ha (2-A to 3-A) water surface ponds were initially stocked at a density of 34,595 juveniles per hectare (14,000 juveniles per acre) (Posadas et al. 2001, 2002). Experimental results also indicated that at stocking densities of 34,595 juveniles per hectare, 1,065 kg/ha (950 lb/A) of 10-count prawns are produced in 0.1-ha (0.25-A) and 0.06-ha (0.15-A) ponds. To simplify assumptions, two stocking densities, 20,000 and 14,000 juveniles per acre (49,420 and 34,595 juveniles per hectare), were used in the economic analysis. The size of prawn farms currently ranges from a few water acres to more than 160 water acres. For the purpose of this analysis, a hypothetical 50-water-acre (20-ha) commercial operation was assumed using 25 appropriately designed, 2-water-acre (0.8-ha) production ponds. Tables 4-5 present the critical biological and economic parameters used in the analysis of hypothetical, risk-free management systems for pond production of freshwater prawn at different levels of investment (dollars per acre). The principal differences between the two pond management systems are stocking density (juveniles per acre), desired harvest size (number per pound), and expected farm-gate price (dollars per pound). As a consequence of lower stocking density, ponds will yield fewer total pounds of prawns per acre. However, the larger individual prawns produced at a lower density can be sold at a higher farm-gate price. Historical, monthly ex-vessel

Table 4. Critical model parameters and simulation results of hypothetical, risk-free freshwater prawn pond management systems with a stocking density of 14,000 per acre under different levels of investment, Mississippi, 2002.

Critical parameters and investment levels	Scenario I[1]	Scenario II[2]	Scenario III[3]
Critical Biological Parameters			
Stocking density (postlarvae/A)	14,000.000	14,000.000	14,000.000
Survival (%)	75.000	75.000	75.000
Desired harvest count (#/lb)	10.000	10.000	10.000
Stocking size (g)	0.150	0.150	0.150
Desired harvest size (g)	45.400	45.400	45.400
Gross feed conversion	2.500	2.500	2.500
Critical Economic Parameters			
Farm-gate price, heads-on ($/lb)	4.000	4.000	4.000
Processing yield, headless (%)	45.000	45.000	45.000
Number of production ponds (#/farm)	25.000	25.000	25.000
Size of production ponds (A/pond)	2.000	2.000	2.000
Experimental-commercial yield gap (%)	92.000	92.000	92.000
Capital outlay index (%)	100.000	100.000	100.000
Model Description			
Number of crops (#/yr)	1.00	1.00	1.00
Operating capital ($/yr)	106,143	106,143	102,259
Initial fixed investment ($)	266,704	215,279	143,733
Number of juveniles stocked (M/yr)	0.70	0.70	0.70
Average shrimp production (heads-on) (lb/A)	966.00	966.00	966.00
Total shrimp production (heads-on) (lb/yr)	48,300.00	48,300.00	48,300.00
Feed required (ton/yr)	60.38	60.38	60.38
Model Results			
Net return above specified expenses ($/yr)	44,588	49,580	64,573
Payback period (yr)	3.910	2.941	1.782
Net present value (10-yr cash flow) ($)	109,170	183,801	302,883
Internal rate of return (10-yr cash flow) (%)	20.003	29.828	54.348

[1]Investment includes pond construction, all machinery, and all land.
[2]Investment includes pond construction and all machinery, but no land.
[3]Investment includes pond construction and aquaculture machinery, but no land.

prices of headless marine shrimp products in the northern Gulf of Mexico and monthly average import prices of frozen headless marine shrimp products published by the National Marine Fisheries Service website (www.st.nmfs.gov/st1/) were used as a basis for determining the most likely farm-gate prices for a heads-on, fresh, on-ice product sold in the prawn commodity markets. Another marketing form that producers can consider is a heads-on and headless individually quick frozen (IQF) product.

Determination of the economic feasibility of an investment project is based upon the internal rate of return (IRR) method. The decision rule is the following: if IRR is greater than or equal to the cost of capital, then the project is accepted. Otherwise, it is rejected. The cost of capital is the interest rate at which money can be borrowed and is based upon the prime rate at which banks borrow money from the Federal Reserve Bank system. Another interest rate that can be used for comparison to the IRR is an investor's expected rate of return, commonly accepted as 25%. This rate is higher than the interest rates of commercial banks because the risk factor of the investment is included. The higher percentage rate used in the decision rule represents a more conservative approach in determining whether to accept or reject a project. The payback period (PP) estimates the number of years necessary to recover the initial investment from the expected annual net income before any allowance for depreciation.

Three different levels of investment adapted from D'Abramo et al. (2002) were used to evaluate the economic feasibility of the CPPS models. Scenario I refers to a CPPS that must invest in newly constructed 2-water-acre ponds, all farm and aquaculture machinery, and newly acquired land (Table 6). Scenario II describes a CPPS with investment on new pond construction and all machinery but with land already owned. Scenario III requires investment on new pond construction and aquaculture machinery only, while general farm equipment and land are already owned.

The base CPPS model labeled as Scenario I requires an initial fixed investment of $266,704 (Tables 4-5). A detailed description of the type, number, and costs of land, pond construction, machinery, and equipment necessary for the base CPPS model is presented in Table 6. With a stocking density of 20,000 juveniles per acre, operating capital amounts to $124,510 per crop (Table 6). Given the base model assumptions, an estimated 57,500 lb of 12-count prawns are produced during a 4-month growout period each year. The estimated average cost of production is $2.90/lb, consisting of $2.17/lb average variable costs and $0.74/lb average fixed costs. The major cost items are juveniles (36%), feed (15%), labor (13%), and repair and maintenance (9%) for operations, as well as depreciation (56%) and interest on investment (37%) for

Table 5. Critical model parameters and simulation results of hypothetical, risk-free freshwater prawn pond management systems with a stocking density of 20,000 per acre under different levels of investment, Mississippi, 2002.			
Critical parameters and investment levels	Scenario I[1]	Scenario II[2]	Scenario III[3]
Critical Biological Parameters			
Stocking density (postlarvae/A)	20,000.000	20,000.000	20,000.000
Survival (%)	75.000	75.000	75.000
Desired harvest count (#/lb)	12.000	12.000	12.000
Stocking size (g)	0.150	0.150	0.150
Desired harvest size (g)	37.830	37.830	37.830
Gross feed conversion	2.500	2.500	2.500
Critical Economic Parameters			
Farm-gate price, heads-on ($/lb)	3.000	3.000	3.000
Processing yield, headless (%)	45.000	45.000	45.000
Number of production ponds (#/farm)	25.000	25.000	25.000
Size of production ponds (A/pond)	2.000	2.000	2.000
Experimental-commercial yield gap (%)	92.000	92.000	92.000
Capital outlay index (%)	100.000	100.000	100.000
Model Description			
Number of crops (#/yr)	1.00	1.00	1.00
Operating capital ($/yr)	124,510	124,510	120,626
Initial fixed investment ($)	266,704	215,279	143,733
Number of juveniles stocked (M/yr)	1.00	1.00	1.00
Average shrimp production (heads-on) (lb/A)	1,150.00	1,150.00	1,150.00
Total shrimp production (heads-on) (lb/yr)	57,500.00	57,500.00	57,500.00
Feed required (ton/yr)	71.88	71.88	71.88
Model Results			
Net return above specified expenses ($/yr)	5,521	10,513	25,506
Payback period (yr)	9.151	6.307	3.455
Net present value (10-yr cash flow) ($)	(109,057)	(34,426)	84,656
Internal rate of return (10-yr cash flow) (%)	-2.365	5.545	24.016

[1]Investment includes pond construction, all machinery, and all land.
[2]Investment includes pond construction and all machinery, but no land.
[3]Investment includes pond construction and aquaculture machinery, but no land.

fixed costs (Table 7). At an average established farm-gate price of $3/lb for a heads-on, fresh on-ice product, annual net return above specified expenses is $5,521, payback period is more than 9 years, and net present value and internal rate of return are negative for Scenario I (Table 5). Scenario I can be considered a benchmark for further economic analysis of CPPS under different technical, biological, and market conditions. At a gross feed conversion (FCR) of 2.5:1, estimated total feed consumption was 71.88 tons per crop (Table 5). The number of 45-day-old juveniles needed for stocking was 1 million per crop (Table 5).

The economic and biological constraints to freshwater prawn aquaculture in the United States can be adequately managed to promote the growth of this emerging industry. Economic feasibility can be enhanced by a combination of revenue-enhancing and cost-reducing measures that include improvement in prawn growth and market development. For example, improvements in farm-gate prices ($1/lb more) due to the production of larger prawns (10-count) influence the economic feasibility of freshwater prawn aquaculture. The combined effects of lower prawn counts, resulting from a lower stocking density management strategy, and higher farm-gate prices on the aquaculture of freshwater prawn are encouraging (Scenario I, Table 4). With a simultaneous improvement in prawn size (20%) and a price increase of $1/lb, pond culture of freshwater prawns is economically viable at a lower stocking density (14,000 per acre) and 50 water acres in operation.

Changes in the levels of investment on CPPS also allow the prawn farmer to realize higher net returns to specified expenses (e.g., land, labor, and management). Scenario II (Tables 4-5) allows growers who already own land suitable for freshwater prawn production to construct new ponds and purchase and install machinery and equipment. Scenario III (Tables 4-5) refers to a farming situation whereby land and farm-wide equipment are already owned, new ponds need construction, and aquaculture-specific equipment must be purchased and installed. The favorable IRR values suggest that these scenarios are economically feasible at initial

Item	Quantity	Unit cost	Total cost	Percent of total	Per pond	Per water acre	Per land acre
		$	$	%	$	$	$
Land and Pond Construction Costs							
Land (acres)	60.50	800.00	48,400	18.15	1,936	968	800
Surveying (acres)	60.50	50.00	3,025	1.13	121	61	50
Earth moving (cubic yards)	62,900.00	0.80	50,320	18.87	2,013	1,006	832
Drainage structure (acres)	50.00	100.00	5,000	1.87	200	100	83
Drain channel (acres)	50.00	50.00	2,500	0.94	100	50	41
Artificial substrates (acres)	50.00	0.00	0	0.00	0	0	0
Gravel (acres)	50.00	43.00	2,150	0.81	86	43	36
Vegetative cover (acres)	5.25	110.00	578	0.22	23	12	10
Subtotal			111,973	41.98	4,479	2,239	1,851
Machinery and Equipment Costs							
Tractor (50 hp)	1.00	20,046.00	20,046	7.52	802	401	331
Truck (1/2 ton, 4x4)	1.00	20,000.00	20,000	7.50	800	400	331
Feed truck (3/4 ton, used)	1.00	5,250.00	5,250	1.97	210	105	87
Dissolved oxygen meter (w/ 12-ft cable)	1.00	800.00	800	0.30	32	16	13
PTO-driven paddlewheel (w/ 540 rpm shaft)	1.00	3,500.00	3,500	1.31	140	70	58
Paddlewheel aerator (2 hp)	25.00	900.00	22,500	8.44	900	450	372
Electrical distribution (acres)	50.00	106.00	5,300	1.99	212	106	88
Side-mounted mower (6 ft)	1.00	4,500.00	4,500	1.69	180	90	74
Truck-mounted feeder (4,000 lb)	1.00	6,500.00	6,500	2.44	260	130	107
Electronic feeder scale (w/ printer)	1.00	3,200.00	3,200	1.20	128	64	53
Feed storage bin (10 ton)	1.00	2,200.00	2,200	0.82	88	44	36
Service building (20 ft X 40 ft)	1.00	27,000.00	27,000	10.12	1,080	540	446
Water supply (w/ 3,000 gpm pump)	1.00	30,000.00	30,000	11.25	1,200	600	496
Chemical boat (14 ft, 42-in bottom)	1.00	1,560.00	1,560	0.58	62	31	26
Outboard motor (30 hp)	1.00	1,600.00	1,600	0.60	64	32	26
Boat trailer (14-in wheels)	1.00	775.00	775	0.29	31	16	13
Subtotal			154,731	58.02	6,189	3,095	2,558
Total Initial Investment Costs			266,704	100.00	10,668	5,334	4,408

Table 6. Estimated initial investment requirements for a 50-water-acre, single-enterprise freshwater prawn pond production system, Mississippi, 2002.

stocking densities of 14,000 per acre. At a 20,000-per-acre initial stocking density, only scenario III is suggested as economically feasible. Recent research results suggest that a stocking density of 8,500 per acre is comparatively the most economically feasible of all three scenarios. This density is sufficiently high to produce a larger, higher priced product and to increase overall production. Likewise, it allows for a reduction in the proportionately highest components of operational costs — the purchase of juveniles and feed.

In summary, a hypothetical commercial pond aquaculture production system was developed based on current information on pond growout technology in the United States. The projected costs and returns of CPPS were estimated based on recommended management practices, biological knowledge of the species, estimated input usage and prices, and established farm-gate prices. Simulation models were developed to evaluate the economic viability of CPPS under different economic and biological scenarios relating to the pond culture of the species in the United States. Further research needs to be directed toward capitalizing on new markets of different product forms, developing improved pond management systems, and solving the logistical problems that accompany the construction and operation of a commercial pond production system.

Table 7. Estimated annual costs of freshwater prawn production in a 50-water-acre, single-enterprise pond production system, Mississippi, 2002.								
Item	Quantity	Unit cost	Total cost	Per pond	Per water acre	Per land acre	Per pound heads-on	Pct. of total
		$	$	$	$	$	$	%
Variable Costs								
Repair and maintenance (acre)	50.00	229.1862	11,459	458	229	189	0.20	9.2
Fuel (acre)	50.00	116.5132	5,826	233	117	96	0.10	4.7
Electricity								
Electric aerators (kwh)	71,200.00	0.0871	6,202	248	124	103	0.11	5.0
Water pump (kwh)	2,871.00	0.0871	250	10	5	4	0.00	0.2
Chemicals (acre)	50.00	104.3050	5,215	209	104	86	0.09	4.2
Telephone expense (acre)	50.00	50.0000	2,500	100	50	41	0.04	2.0
Juveniles (1,000 pieces)	1,000.00	45.0000	45,000	1,800	900	744	0.78	36.1
Feed (ton)	71.88	256.0000	18,400	736	368	304	0.32	14.8
Labor (hr)	2,275.30	7.0000	15,927	637	319	263	0.28	12.8
Crushed ice (lb)	57,500.00	0.0600	3,450	138	69	57	0.06	2.8
Hauling (lb)	57,500.00	0.0568	3,266	131	65	54	0.06	2.6
Miscellaneous (pond)	25.00	50.0000	1,250	50	25	21	0.02	1.0
Operating interest ($)	115,294.9000	5.00%	5,765	231	115	95	0.10	4.6
Total Variable Costs			124,510	4,980	2,490	2,058	2.17	100.0
Fixed Costs								
Depreciation			23,622	945	472	390	0.41	55.6
Interest on investment			15,755	630	315	260	0.27	37.1
Taxes and insurance			3,091	124	62	51	0.05	7.3
Total Fixed Costs			42,469	1,699	849	702	0.74	100.0
Total Costs			166,979	6,679	3,340	2,760	2.90	

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