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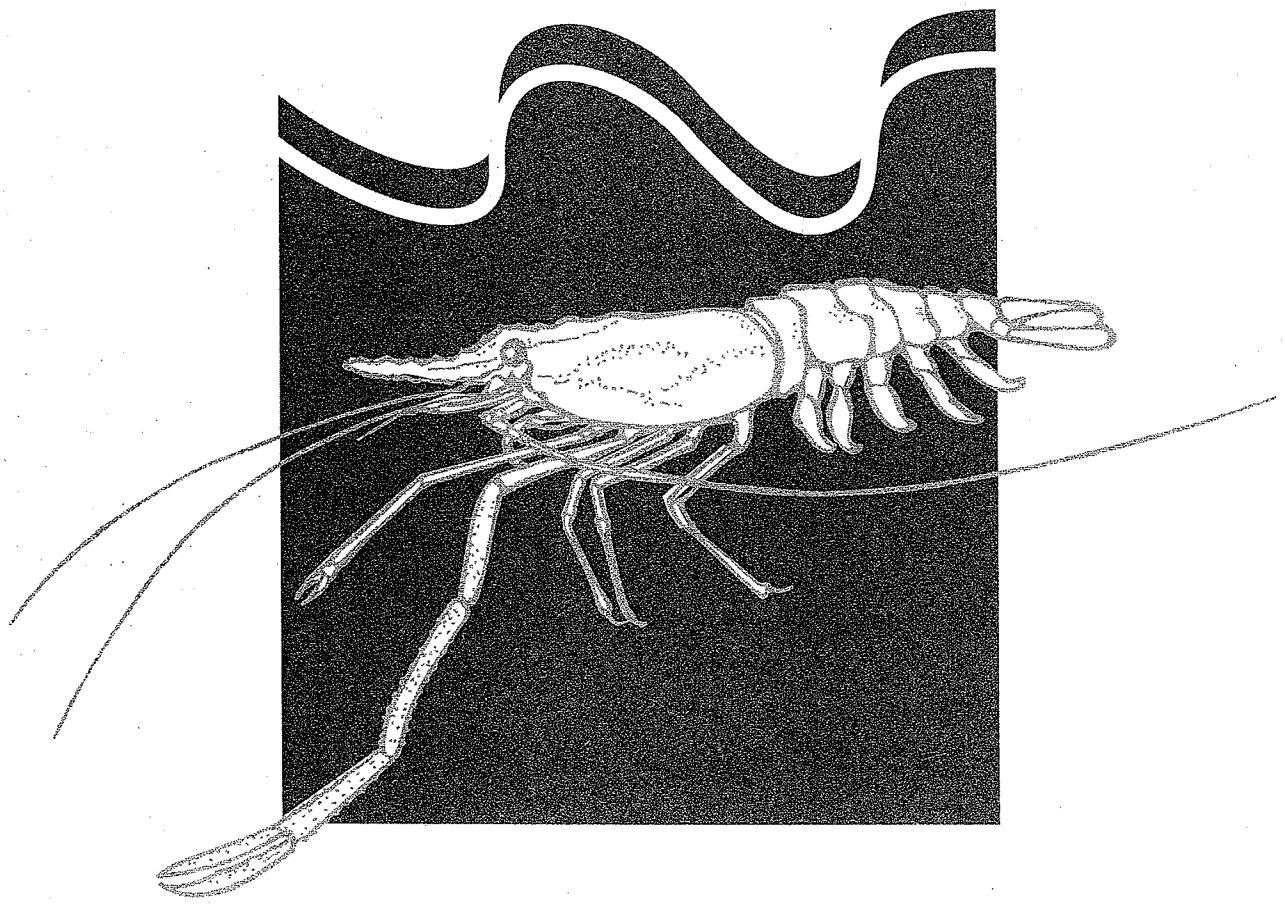
MANAGEMENT PRACTICES

for Culture of

FRESHWATER *Prawns*

IN TEMPERATE CLIMATES



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Management Practices for Culture of Freshwater Prawn (*Macrobrachium rosenbergii*) in Temperate Climates

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Management Practices for Culture of Freshwater Prawn (*Macrobrachium rosenbergii*) in Temperate Climates

Commercial production of freshwater shrimp or prawn (*Macrobrachium rosenbergii*) has often been the subject of research and commercial enterprise in the United States. Basic production techniques were developed in the late 1950's in Malaysia, and in Hawaii and Israel during the last three decades. In 1984, the Mississippi Agriculture and Forestry Experiment Station 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 10 years. It has been prepared to provide a detailed description of the procedures necessary for successful completion of the three phases of culture (hatchery, nursery, and pond growout) of the freshwater prawn, *M. rosenbergii*, in temperate climates. The bulletin also provides important information concerning the biology of the species as well as supplies and equipment necessary for successful culture.

During the period of evaluation, the prospects for an economically successful prawn industry have increased dramatically because of development of improved management practices. These practices, for the first time, manage for the biology of the prawn and represent an efficient use of both manufactured feed and natural food as sources of nutrients in the pond growout phase. For the pond growout phase, research efforts have been complemented by demonstration projects designed to evaluate methods under large-scale, commercial-type conditions. These projects have validated the results achieved under small-scale experimental conditions.

Life History

Growth

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

Breeding

Females generally become reproductively mature within 6 months of age. Mating can occur only between hard-shelled males and soft-shelled females, ie. females that have just completed a premating or prenuptial molt. The male deposits sperm held in a gelatinous mass underneath the body of the female between her fourth pair of walking legs.

Within a few hours after mating, eggs are released and fertilized by the sperm. The female then transfers the fertilized eggs to the underside of the abdomen (tail) in a "brood chamber" formed by swimming appendages. The eggs are aerated and cleaned by movement of these appendages and remain attached to the abdomen until they hatch.

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

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

Larvae

After hatching, larvae are released and swim upside down and tail first. The larvae cannot survive in fresh water beyond 48 hours and must migrate to brackish water. Larvae are very aggressive sight feeders and feed almost continuously, primarily on small zooplankton, large phytoplankton, and larval stages of other aquatic invertebrates. Larvae undergo 11 molts, each representing a different stage of metamorphosis. Following the last molt, larvae transform into postlarvae. The time period necessary for transformation from a newly hatched larva to postlarva depends upon food quantity and quality, 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 lb). The prawns behaviorally change from free-swimming stages inhabiting the water column (pelagic) to a principally crawling, bottom-inhabiting stage (benthic). When they do swim, they move like adults with the dorsal (back) side uppermost and in a head-forward direction.

Postlarvae can tolerate a wide range of salinities and migrate to fresh water. In addition to the food they ate as larvae, larger pieces of both animal and plant material are now consumed. The diet includes larval and adult aquatic insects,

algae, mollusks, worms, fish, and feces of fish and other animals. At high densities or under conditions of food limitation, prawns become cannibalistic.

Postlarvae are translucent, and as they change to the juvenile stage, they take on the bluish-green to brownish color of the adult stage. Juveniles are intermediate in size to postlarvae and adults; however, no standard definition for the juvenile stage exists.

Adult

Older juveniles and adults usually have a distinctive blue-green color, although sometimes they may take on a brownish hue. Color is usually the result of the type of diet. Adult males and females are easily distinguishable. 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, a wide gap exists between the last pair of walking legs. Females have a genital opening at the base of each of the third pair of walking legs.

Three different types of adult males have been identified based upon external characteristics. Easily distinguishable are the blue claw (BC) males, characterized by long, spiny blue claws. Two other classes of non-blue claw male morphotypes exist, orange claw (OC) and strong orange claw (SOC) males. The transformational sequence is from OC to SOC to BC male. Some smaller OC males, < 10g (0.35 oz) whole body weight, grow very slowly but have a greater role than other OC males in reproductive activities.

BC males and some of the smaller OC males are the most reproductively active and most successful at mating. The BC male maintains a territory associated with a group of females that are ready for mating and protects them during a vulnerable period just before and after molting. Small OC males will eventually grow and advance to the SOC (strong orange claw) stage and finally into BC forms. BC males undergo an extended period of non-molting (anecdysis). As the BC ages, reproductive capacity diminshes. Eventually, the BC male molts and returns to a growth phase during which its reproductive capacity is renewed.

Management Practices

The three phases of freshwater prawn culture are hatchery, nursery, and pond growout. Anyone who is contemplating the starting of a prawn production enterprise should temporarily forego at least the hatchery phase, and possibly the nursery phase, and purchase juveniles for pond stocking from a supplier. The hatchery and nursery stages are shorter, but more labor-intensive phases. Therefore, plans for development of a nursery phase and possibly a hatchery should follow only after repeated successful pond growout attempts and expansion of growout area. A limited number of suppliers of juvenile prawns currently exists and an increase in demand will eventually lead to more enterprises that exclusively produce and sell seed (analogous to producers of fingerlings for stocking production ponds in the catfish industry).

Hatchery/Seedstock

Procurement of seedstock. Production of seedstock of freshwater prawns begins with maintenance of a healthy broodstock population. In temperate climates, broodstock should be obtained from the harvest crop and transferred to tanks or raceways located within a temperature controlled building. Water temperature for broodstock holding should be between 25 (77 °F) and 28 °C (82.4 °F). Broodstock should be stocked at a density of lg/L (1.15 oz/gal) at a ratio of 10 females to 2 to 3 males. For every BC male, there should be 3-4 OC males, assuming a 4-5 month holding period before collection of egg-bearing females for larval production. Broodstock should be fed a 35% protein, high energy, 3.0 kcal /g (85 kcal/oz), pelleted diet containing at least 0.5% highly unsaturated fatty acids (a commercially available salmonid feed would be suitable). They should be fed at a rate of 1-3% of their body weight per day, divided into 2-3 feedings of equivalent amounts. Holding tanks or raceways should be equipped with structures that will allow maximum use of the entire water column by prawns to separate and inhabit.

A mature female produces approximately 1,000 eggs/g (28,571 eggs/oz) of wet weight. At the recommended range of holding temperature, a series of color changes from bright yellow to orange to brown to a grey-green characterizes development of the eggs. Grey-green colored eggs will hatch within 24-72 hours. Females with eggs in the advanced state of development can be removed from partially drained holding tanks and directly transferred to special hatching tanks (Figure 1) that contain water of similar temperature and a salinity of 0-5 g/L (ppt) and where eggs usually hatch at night. By positioning a low intensity light above the overflow pipe, larvae are attracted and thereby collected in a separate, adjoining tank. A small mesh screen, 90-120μm (3.5×10^{-5} to 4.7×10^{-5} in), on the overflow pipe prevents larvae from escaping from the collection tank. Water from the collection tank then flows either to another tank or back to the hatching tank.

During the following day, the concentration of larvae in the collection tank is determined and the appropriate number of larvae are transferred to rearing tanks at an initial stocking density ranging from 50-80/L (189-300/gal). Larvae should be collectively stocked from eggs hatched during a 1- to 4-day interval. A following day's group of larvae should only be stocked after those stocked the previous day have been fed and there is evidence of at least partially full guts. This procedure minimizes cannibalism of late-stocked individuals by earlier-stocked individuals and ensures that a smaller range of larval stages occurs at any one time during the culture period. The duration of the period of postlarval harvest is also minimized if a narrow range of larval stages (sizes) is maintained.

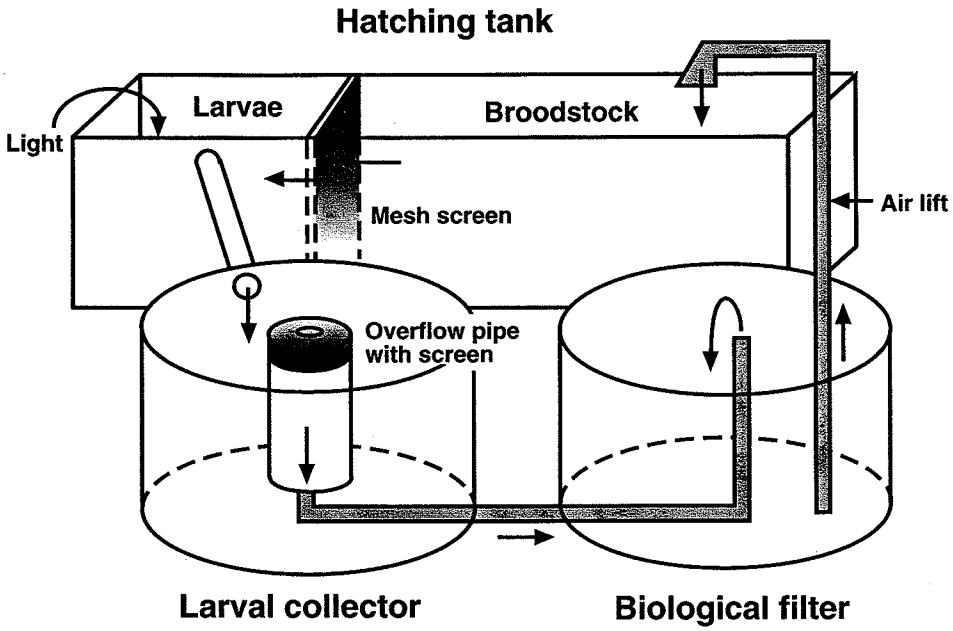

Figure 1. Design of larval hatching and collection unit (→ =water flow).

Culture conditions. Larval culture must be conducted under indirect light with an intensity ranging from 30,000 to 700,000 lux, a level typical of a partly cloudy to a clear day. Natural light is supplemented by intense artificial light daily during the early morning and late afternoon. Artificial light should never be used as an exclusive substitute for natural light.

Larvae may be cultured in recirculating systems (Figure 2) at a water temperature of 28-30 °C (82.4-86 °F) and a salinity of 12-15 g/L (ppt). Use of recirculating systems allows for efficient use of water and reduction of heating costs. Recirculating systems require a biological filter to avoid accumulation of nitrogenous waste products (ammonia, nitrite) that can be toxic at certain concentrations. Biological filters consist of a high surface area substrate (media) upon which bacteria live and transform ammonia, the principal waste product of larval prawns, to nitrite and then to nitrate.

The larval culture system should be cleaned, sterilized and flushed prior to initial filling. Water used for the initial filling should pass through a 5- micron bag filter. After the system is filled and operational, a chlorine-based sterilizing agent should be added to achieve a chlorine concentration of 5 mg/L (ppm). If this sterilization procedure is performed several days before stocking, dechlorinating agents (ie., sodium thiosulfate) are not required. Such a protocol is recommended because the presence of dechlorinating agents has been implicated with mortality of prawn larvae. If only freshwater is available, a commercially available salt mixture must be added and thoroughly mixed with the freshwater to achieve the appropriate salinity for culture. Proven high quality marine salt mixtures should only be used because salt mixtures can differentially affect growth and even cause mortality.

Water in the larval culture system is pumped from a collecting reservoir (sump) through a sand filter, passing an ultraviolet light unit and through a biological filter before it enters into the tank where the larvae are cultured (Figure 2).

The volume of the biological filter should be approximately 6% of the volume of the entire culture system. The rate of water flow through the biological filter should be 30 to 100% of the volume of the entire system/hour. Highest stocking rates of newly hatched larvae (100/L) will require the highest flow rates (70 to 100% of the total water volume per hour).

The sand filter should contain sand particles of an 850-micron size to achieve efficient removal of particulate matter before the water is again exposed to the ultraviolet light unit and the biological filter. The removal of particulate matter from the water increases the efficiencies of the ultraviolet light and biological filter. The ultraviolet light exposure dramatically reduces the concentration of bacteria and accordingly reduces the incidence of pathogenic bacteria. The sand filter must be flushed (backwashed) once to several times daily, depending upon the size of the larvae and the amount of food fed, to avoid accumulation of particulate organic material that can clog or cause channeling, thereby reducing the efficiency of removal.

Other types of systems designed for the removal of particulate material from recirculating systems are available. Daniels et al. (1992) have provided details concerning require-

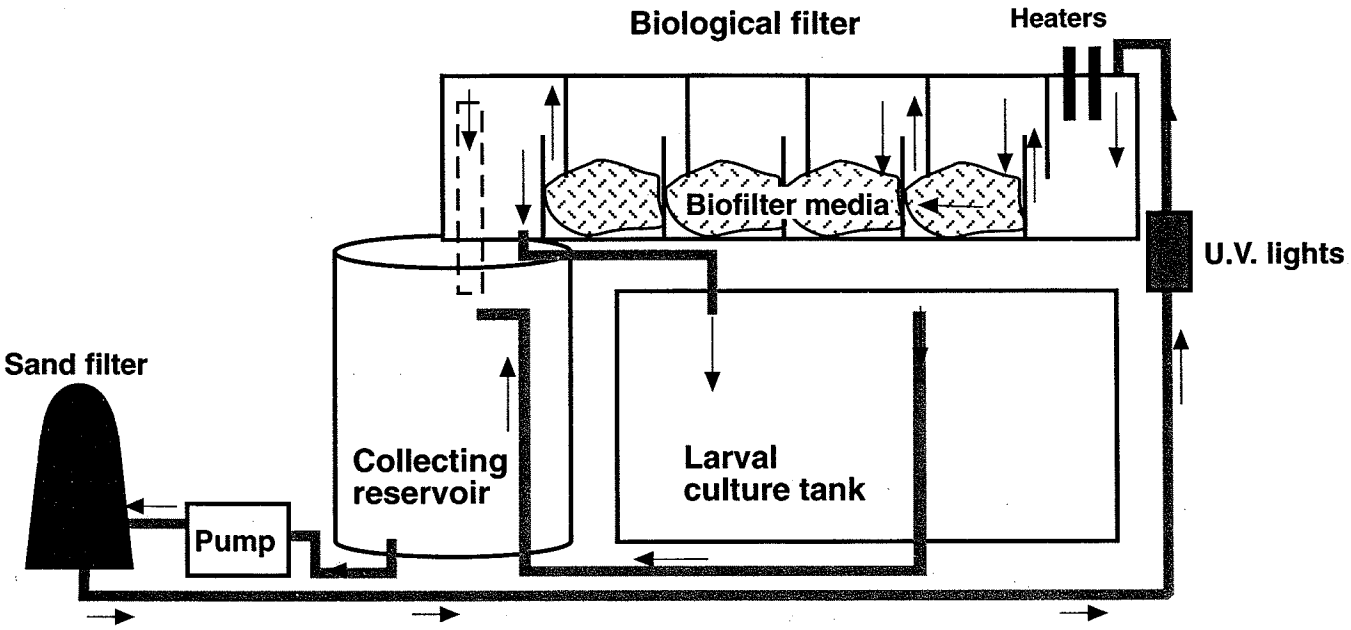

Figure 2. Design of larval culture unit.

ments for materials and equipment given a specific production goal.

Preparation and Maintenance of the Media for the Biological Filter. The water volume of the biological filter should be at least 6% of the volume of the culture tanks that it will serve. A variety of biofilter media can be used. However, the media should provide a large surface area for bacterial growth with a portion consisting of calcareous material such as small crushed oyster shell or coral. Media should be held in bags fashioned from fiberglass window screen to facilitate storing and handling.

The biological filter media are activated in a separate preconditiong container by introducing other media that already have established populations of nitrifying bacteria. Once appropriately conditioned, quantities of the biofilter media are transferred to the actual biological filter unit as needed (ie. as the biomass of the larvae and rate of ammonia production in the culture tank increase). Temperature, 28-30 °C (82.4-86.0 °F), and salinity, 12 g/L (ppt), in the culture and activating tanks should be the same; constant vigorous aeration is required. The procedure for activation of media for the biological filter, adopted from Daniels et al. (1992), follows:

1. Determine the expected daily maximum ammonia-nitrogen load in the larval culture system based on the anticipated number of postlarvae to be produced. Based on empirical data, the maximum rate of production of ammonia-nitrogen (ammonia-N) in a closed, recirculating system for *M. rosenbergii* larviculture is about 30μg/larva/day (1.05×10^{-6} oz/larva/day). For example, if 60 g (2.12 oz) of ammonia-N is the maximum expected amount produced by 2 million larvae within the system in a 24-hour period, then 226.8 g (8.00 oz) of ammonium chloride — because 1.0 g (.035 oz) of ammonium nitrogen exists in 3.78 g (0.133 oz) of ammonium chloride— needs to be oxidized completely by the biofilter media being "activated" in the pre-conditioning tank. A bag of crushed coral weighing 2.26 kg (4.98 lb) usually contains a population of nitrifying bacteria that will nitrify (oxidize) 1.0 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. Maximum volume of coral media, representing less than 4% of the total rearing volume, is reached by the 17th day of rearing or a larval stage index= 8.5 (Griessinger et al., 1989).
2. Initially, 10% of the total required ammonium chloride (NH_4Cl) or another inorganic source of ammonia is added to the water containing the media.
3. After a few days, check the levels of total ammonia-N and nitrite-N (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 as in #2. If either total ammonia or nitrite is still present, do not add any additional ammonium chloride and recheck after another 24 hours.
4. Continue to add the predetermined amount of ammonium chloride (see #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 same procedure.
5. As each level of ammonia is consumed within the desired 24-hour period, double the amount of ammonia 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) 1.0 g (0.035 oz) of ammonium chloride in 24 hours.

6. Once oxidation of the maximum load is achieved, the production cycle can begin. As the media are removed, the amount of ammonia needed for maintenance decreases. However, the nitrifying bacteria on the media remaining in the preconditioning tank must still be maintained at their maximum level of ammonia and nitrite consumption.

Feeds and Feeding. No dry, nutritionally complete, artificial diet for consistently successful larval culture of *M. rosenbergii* currently exists. Therefore, live food must be used. Newly hatched nauplii of *Artemia* (brine shrimp) have been successfully used 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, but can also introduce disease organisms into the larval culture tank. Therefore, cysts should be sterilized, fully or partially decapsulated, and hatched under clean conditions. One procedure to accomplish these requirements follows:

1. **Cyst hydration.** Cysts are hydrated by immersion in fresh or sea water <35g/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)/L of hydration water. Cysts remain in the sterilizing bath for 20 minutes.
3. **Washing and deactivation.** Cysts are placed on a 120-micron (0.0047-inch) screen and thoroughly washed with fresh water or sea water until the odor of chlorine is no longer detected. Toxic chlorine residues that may adsorb to the decapsulated cysts can be deactivated by dipping them two times into a 0.1 N hydrochloric acid (HCl) or acetic acid (CH_3COOH) solution as recommended by Bruggeman et al. (1980). The deactivation should be performed no more than one-half minute and be followed by another washing of the cysts. During the decapsulation process, the cysts should be kept away from direct sunlight.

Hatching of cysts is best achieved in conical bottom, funnel-shaped, PVC containers that are equipped with a valve at the narrow end to facilitate separation and removal of nauplii and wastes. Cysts should be stocked at ≤ 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 medium can be enriched with 2 g/L (ppt) of sodium bicarbonate ($NaHCO_3$). The pH should not drop below 8 and temperature should be kept within the range of 25 to 30 °C (77 to 86 °F). Aeration should be provided to maintain dissolved oxygen levels above 2 mg/L (ppm). The hatching containers should be well illuminated from above with four 60-watt fluorescent light bulbs (1,000 lux) at a distance of 20 cm (7.87 in). After approximately 24 hours, hatched *Artemia* nauplii are harvested according to the following procedure.

1. Turn off air, remove standpipe (if one is used), heater, and airstones and cover the top of the container with a dark lid or black plastic for 15 to 20 minutes. Unhatched cysts and egg shells will rise to the surface and be dark brown. *Artemia* nauplii are bright orange and are located near the bottom of the hatching container or within the water column.
2. Slowly drain the water containing the newly hatched nauplii from the bottom of the container through a 120-micron (0.0047-inch) mesh screen until the dark brown *Artemia* egg shells begin to appear.
3. Thoroughly rinse nauplii collected on the screen with fresh or brackish water.
4. Newly hatched nauplii arising from 50 g of hatched cysts can be safely stored in 1 L of sea water held within an insulated container and chilled to not less than 5 °C by the introduction of ice packs. This procedure decreases the metabolism of the nauplii, thereby preserving a high nutritional value.

The hatching rate of cysts varies according to storage time and conditions as well as geographical origin and commercial brand.

Generally, 150,000 hatched *Artemia* nauplii can be obtained from 1 gram of cysts. Most prawn larvae begin feeding one day after hatching (larval stage 2). Frequent feedings of live food, *Artemia* nauplii, from sunrise to sunset rather than one or two feedings spread over a long period of time, should be practiced because nutritional value of *Artemia* in the water column will decrease over time as the *Artemia* remove the nutrients contained in the yolk sac.

Generally the initial feeding of the prawn larvae consists of newly hatched live *Artemia* that have been retained in a 120-micron harvest screen. The *Artemia* nauplii should be intially fed at a rate of 6-8/larva/day. The initial feeding should consist of 40% of the total *Artemia* to be fed that day, followed by 20% of the total late in the morning. The remaining 40% of the daily ration is fed during the afternoon. A suggested feeding rate of nauplii according to day post-stocking and stage index is presented in Table 1.

No later than mid-morning, a sample of 50 to 100 larvae should be collected and examined under a dissecting microscope to determine whether their guts are full. Full or mostly filled guts indicate healthy individuals. Empty or almost empty guts are an indicator of poor culture conditions such as poor water quality, high levels of bacteria, or insufficient levels of food provided. Care should be exercised to ensure that guts remain full.

Excess *Artemia* that are produced should be frozen in ice cube trays to be available for use during early morning or when poor hatches occur.

Supplemental feed. Supplemental feed is usually provided during mid-morning and late afternoon, approximately 7-10 days after a larval cycle begins. The guts of the larvae should be as full of *Artemia* as possible prior to provision of supplemental feed. During supplemental feeding, a large-mesh screen (150, 400, or 710 microns, depending upon the size of the nauplii) is positioned around the standpipe to allow uneaten *Artemia* and feces to be flushed from the culture tank. Ingredient composition of a typical supplemental diet is fish

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

Day of cycle	Stage index	# *Artemia* /Larva		Supplemental Feed		Particle size	Flushing screen
				upper	lower		
		AM	PM	(mg)	(mg)	(μm)	(μm)
1	1	0	0	-	-	-	250
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	03 .		

or squid, chicken eggs, beef liver powder, and a marine fish oil that should contain a comparatively high level of highly unsaturated fatty acids (Table 2). A recommended procedure for the preparation of supplemental feed 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, or clean fish by removing scales, skin, and bones. Sterilize via 7-8 min/kg (3.18 min/lb) on high setting in microwave. Homogenize fish or squid in a commercial-grade food processor until well-blended (i.e.,smooth texture with no chunks).
2. Mix chicken eggs, marine fish oil, and beef liver powder well and then add to squid or fish homogenate in food processor.
3. Add a binder ingredient (e.g., alginate) gradually and continue mixing slowly until the paste that is formed begins to form balls and detaches from the walls of the food processor.

Table 2. Ingredient composition of supplemental diet.

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

4. Take the paste and form thin patties manually or with a press and place in a plastic bucket containing about 4-5 g/L (ppt) of calcium chloride($CaCl_2$). Extra $CaCl_2$ can be added to the water to increase the rate of binding. The outer layer of paste will begin to harden quickly. After the outer layer of the patties assumes a rubber texture, press a patty between your hands and then slide your hands in opposite directions. This procedure will result in the formation of a thinner patty. After the patties have been separated and have attained a rubbery texture they are processed in a food mill. Later in the larval cycle, the food mill should be replaced with a 1.6-mm (1/16-inch) cheese grater. This procedure will result in an increase in the number of larger particles obtained from the mixture produced. If smaller particles are desired, manually push the material through sieves to obtain proper 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-inch), and 1,000-micron (0.039-in). Rinse the sieved diet thoroughly to remove fine particles, which can foul the water and contribute to bacterial growth within the culture tank. Drain the feed before storing either refrigerated (several days) or frozen. The size of particle fed normally ranges from 250 to 1,000 microns (0.012-0.039 in) depending on the size of larvae (Aquacop, 1977).

Separation of Larvae and Postlarvae. After 11 larval stages have been completed, larvae metamorphose into postlarvae (PLs). After a significant proportion of larvae (25-33%) transforms to postlarvae, the remaining larvae are transferred to another culture tank so that postlarvae can be prepared for transfer to the nursery phase of culture. Generally, two or three transfers of larvae occur per production cycle. Separation should be conducted during the mid to late morning after postlarvae have eaten and are clinging to the wall of the culture tank. Larvae are localized in a feeding ring around the circumference of the tank. Larvae are netted from this area of concentration and moved to another tank. Care should be exercised to ensure that water in the transfer tank has the same qualities.

After the transfer has been completed, pump one-half to two-thirds of the water where the postlarvae remain to another holding tank and sterilize for future use. The postlarvae are now ready for acclimation to fresh water. Fresh water should be added gradually so that the salinity eventually decreases to 0 ppt within a 24- to 36-hour period. At that time, the mean weight of individual postlarvae should be determined by counting and weighing a sample of postlarvae. In order to estimate the total number of postlarvae produced per production cycle and control the density stocked into tanks in the nursery phase, weigh the groups of postlarvae collected as they are transferred to the nursery. Knowledge of the total biomass (weight) harvested and the mean individual weight will permit an estimate of numbers stocked. Generally, survival in the hatchery culture phase ranges from 40 to 80%.

Nursery

A nursery, also referred to as postlarval or juvenile, phase of culture has become a standard part of culture practices for many commercial aquaculture species. This phase was originally developed for *M. rosenbergii* culture in temperate climates to increase the length of the growing season, which is limited by water temperature in production ponds. This phase has also been adopted to produce larger animals for stocking so that stocking mortality caused by predation might be reduced. The nursery phase has also been used as a management practice in tropical climates to increase stocking size.

Nursery culture can be accomplished in a variety of ways, including small ponds or tanks enclosed in climate-controlled buildings. To conserve water and heat, water recirculation systems are recommended, but flow-through systems equipped with heaters can also be used. The depth of the ponds or tanks (pools) should not exceed 1.2 m (4 ft) and they should be equipped with structure (artificial habitat) throughout the water column to increase the total available surface area. A wider distribution of the prawns is achieved, significantly reducing the incidence of cannibalism.

To achieve the best growth and survival, an initial stocking density of not greater than 5-6 postlarvae/L (19-23 postlarvae/gal) is recommended, and water temperature should range between 25-28 °C (78.8-82.4 °F). Postlarvae may be fed a commercially available trout diet containing a high level of crude protein and energy and being a particle size that can be readily consumed. A feeding schedule based on percent of body weight and an empirically derived growth curve for *M. rosenbergii* during the nursery phase of culture are provided in Figure 3. The total daily ration is divided into two separate feedings, morning and afternoon.

Three times per week frozen beef liver is fed as a substitute (on a dry weight basis) for one of the trout diet feedings. The level of the daily ration may need to be adjusted based upon the observed amount of food consumed.

Under these culture conditions, the nursery phase should produce individuals with a mean individual weight of 0.3 g (.011 oz) within 50-60 days. The nursery phase should not exceed 60 days because of the increased incidence of mortality by cannibalism as the individual mean weight increases, and the increased potential for the occurrence of adverse conditions of water quality. Generally, a 65-75% survival can be expected at the end of the nursery phase.

Size grading of nursery populations. Size grading of juveniles from nursery-grown populations prior to stocking into production ponds has been found to be an effective method for increasing individual mean harvest weight and total yield over those achieved with ungraded individuals. Size grading is a practice that has increased the prospects for economically successful freshwater prawn culture.

This stock manipulation procedure separates faster and slower growing prawns, ultimately disrupting the typical social hierarchy formed among males. When these separate populations are transferred to production ponds, growth of smaller males is no longer negatively impacted by the faster growing individual males. Smaller males may thereupon increase growth rates to compensate for the initial retarded growth rates (compensatory growth) that developed during the nursery phase. The result at harvest is a dramatic reduction in the range of sizes, particularly due to the reduction in the percentage of small males that are generally considered

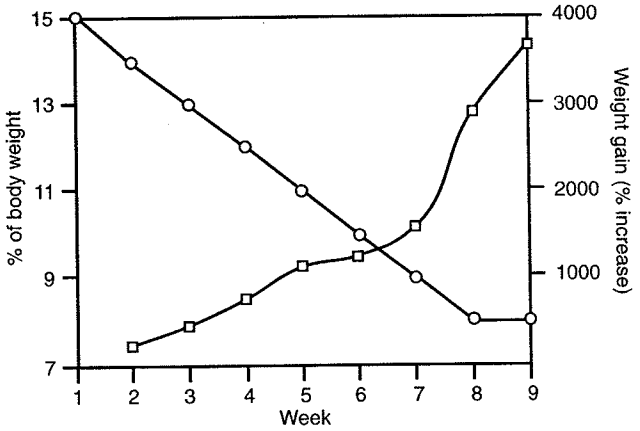

Figure 3. Feeding rate (% of body weight) and growth rate of postlarvae during indoor nursery phase of culture. Postlarvae initially stocked at 5-6/L.

to be of low or no market value for this species. Accordingly, total yield and potential revenue increase.

Size grading can be performed with either bar graders used to grade fish or a suitably modified bar grader design. The type of separation achieved will depend upon bar width as well as the weight (size) distribution of the population of prawns. Experiments have demonstrated that a good relationship exists between bar width and mean weight of the largest prawns that pass through oriented parallel to the bars. 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 the entire population can be used for stocking. However, even both populations arising from a 70%-30% (upper-lower) separation have been successfully used.

Size grading should be conducted with sufficient aeration to avoid stressful conditions. Juveniles move toward a flow of water and this behavior may assist in the development of passive grading techniques. Other more active grading techniques would involve the movement of a grader through a population or the movement of a population through a stationary grader. No specific grading procedure is recommended. The choice would be based upon the experience and resources available to the culturist.

Growout

Postlarvae or juveniles for the pond growout phase can be purchased through commercial hatcheries currently located in Texas, California, and Mexico. The price varies according to size and quantity desired, but is approximately U.S. $60 per 1,000 juveniles. Shipping costs can be minimized if the hatcheries are located within a 10- to 14-hour driving distance of your growout facility.

Pond design and preparation. Ponds used for raising freshwater prawns should have many of the same 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 important considerations. Well water is the preferred water source for raising freshwater prawns. Runoff from rivers, streams, and reservoirs can be used, but quality and quantity may be highly variable and not subject to control. The quality of the water source should be evaluated before any site is selected. Some initial water quality characteristics considered absolutely necessary for good prawn growth include a pH range of 7.0 to 8.5 and a water hardness range of 15-150 mg/L (ppm). Ponds should be located in areas that are not subject to periodic flooding.

Prawns are sensitive to many of the pesticides used on row crops; therefore, before building ponds specifically for producing freshwater prawns, the soil should be analyzed for the presence of pesticides. Also, avoid use of ponds that are subject to drift from agricultural sprays or to runoff water potentially contaminated with pesticides. Water samples should also be screened for pesticide contamination.

The surface area of growout ponds should ideally range from 0.4 to 2.0 hectares (1 to 5 acres); however, larger ponds have been successfully used. The pond should have a rectangular shape to facilitate distribution of 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. Ponds should have a minimum depth of 0.6 meter (2.15 feet) at the shallow end and slope to a maximum depth of 1-1.2 meters (3.28-3.93 feet). The slope of the pond bottom should allow for rapid draining. Assistance in pond design and layout can be obtained by contacting the local office of the Soil Conservation Service.

A soil sample should be collected from the pond bottom to determine if an application of lime is needed. Soil samples should be obtained from about six different places in the pond and mixed together to make a composite sample. The sample should be placed in a soil sample box, available from county offices of the Cooperative Extension Service, and sent to your state Extension Soil Testing Laboratory or another soil testing laboratory. A test for a lime requirement of your pond will then be performed. If the pH of the soil is less than 6.5, an application of agricultural limestone will be needed to increase the pH to a minimum of 6.5, preferably to 6.8.

Fill the ponds and then, if necessary, fertilize them to stimulate production of an abundance of natural food organisms for the prawns and to shade out unwanted aquatic weeds. A liquid fertilizer, either a 10-34-0 or 13-38-0, gives the best results and should be applied at a rate of 1.9 L (1/2 gallon) per surface acre to the pond at least 1-2 weeks before stocking of juvenile prawns.

At least 1 or 2 days before stocking the juvenile prawns, the pond should be checked for aquatic insect adults and larvae. These potential predators can be controlled by applying a 2:1 mixture of motor oil and diesel fuel at the rate or 3.78-7.57 L (1-2 gal) per surface acre on a calm day. The oil film on the water kills air-breathing insects that need to come to the surface to breathe.

If a water source other than well water is used to fill a pond, fish, such as bass, bluegill, and green sunfish, must be prevented from entering the pond. The fish may prey upon the prawns, particularly juveniles. Fish can be eradicated by applying 3 pints (1.41 L) of 5% emulsifiable rotenone per acre foot of water. After application, the rate of breakdown of rotenone, which can be potentially toxic to prawns, is influenced by temperature, light, levels of dissolved oxygen, and alkalinity. Generally, stocking of prawns can proceed 2 to 3 weeks after application.

Stocking of juveniles. Juveniles should be acclimated to pond conditions by gradually replacing water in which they are being held with water into which they will be stocked. This procedure should be continued until the difference between the temperature of the holding system and the ponds is less than 3 °C (5.4 °F).

To avoid stress caused by low temperature, prawns should be stocked when the temperature of the pond water is consistently $\geq$20 °C (68 °F). Mortality of juvenile prawns is

risked if a rapid decrease in temperature to <15.6 °C (<60 °F) occurs.

Juveniles, preferably those derived from size-graded populations, ranging in weight from 0.1 to 0.3 g (.003 to .011 oz), should be stocked at densities ranging from 28,920 to 39,535/ha (12,000 to 16,000/A). Lower stocking densities will yield larger prawns but lower total harvested weight. The duration of the growout period is dependent on the water temperature of the ponds and generally ranges from 120 to 150 days in central Mississippi. Prawns could be grown year-round, possibly two crops/year, provided a water source having a sufficiently warm temperature for growth is available.

Feeding. Juvenile prawns stocked into earthen growout ponds at the previously stated densities are initially able to satisfy nutritional requirements from consumption of natural pond biota such as insect larvae and worms. At the recommended stocking densities, feeding should commence when the average weight of individuals in the pond population is 5.0 g (0.176 oz). Commercially available sinking channel catfish feed (32% crude protein) has been determined to be effective at the recommended stocking density. Feeding rate is principally dependent upon the mean weight of the population (Table 3).

A feeding schedule has been developed by researchers at the Mississippi Agricultural and Forestry Experiment Station and is based upon three factors: (1) a feed conversion ratio of 2.5:1, (2) 1% mortality in the population per week, and (3) mean individual weight derived from samples collected during the growout season. At the end of the growout season, survival generally ranges form 60 to 85% when maintenance of good water quality has been practiced. Yields typically range from 670 to 1,350 kg/ha (600 to 1,200 lb/A) and mean weight of individual prawns ranges from 28 to 36 g or 36-28 prawns/kg (16-12.5 prawns/lb).

Water Quality Management. Water quality is just as important in achieving maximum production of freshwater prawns as it is in catfish culture. Dissolved oxygen is particularly important, and a good oxygen monitoring program is necessary. Levels of dissolved oxygen should be routinely monitored at the bottom one foot (0.3 m) of water where the prawns generally live.

Electronic oxygen meters are the most reliable and accurate means to determine levels of dissolved oxygen but 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 is greater as the quantity of ponds to be managed increases.

With only one or two small ponds, a chemical oxygen test kit that will perform 100 tests will suffice. These text kits are commercially available from several distributors. Water samples from different depths can be collected for dissolved oxygen analysis with either commercially available or individually fashioned devices.

Dissolved oxygen concentrations less than 3 mg/L (ppm) are stressful and lower concentrations can be lethal. Therefore, levels of dissolved oxygen concentration in the bottom one foot (0.3 m) of water should not fall below 3 mg/L (ppm). Chronically low levels of dissolved oxygen will result in less than anticipated yields at the end of the growing season. Emergency aeration can be achieved by an aerator. The design and size of the aerator will be principally determined by the size and shape of the culture pond.

Late evening or early morning dissolved oxygen depletions can be avoided by simply recording the level of dissolved oxygen an hour after sunset and approximately 2 hours later. These two readings are then plotted on a piece of graph paper and connected with a straight line. By extending the line from these two points over time, the dissolved oxygen concentration before daylight (5-6 a.m.) can be estimated. Such a procedure identifies whether the level of dissolved oxygen will likely decrease to either stressful or lethal conditions and indicates whether emergency aeration will be necessary. However, dissolved oxygen levels do not always decrease in a constant linear pattern and late evening or early morning dissolved oxygen determinations are recommended.

Specific information on 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, a softening of the shell was noticed. Hardness should range between 50 and 200 mg/L (ppm). Hard water, 300 mg/L (ppm) or higher, is not recommended because it has been implicated in reduced growth and lime encrustations on the exoskelton. Hardness in pond water can be increased through the application of a source of calcium such as agricultural gypsum or calcium chloride. Gypsum is generally more readily avaliable than calcium chloride. The purity of gypsum varies (70-98%), but if a 100% purity is assumed, then an application rate of 1.72 mg/L (ppm) will achieve an increase of 1.00 mg/L (ppm) in total hardness.

Nitrogenous Compounds. Nitrites at concentrations of 1.8 mg/L (ppm) have been associated with mortality in hatcheries but no definitive information concerning the toxicity of nitrite to prawns in pond situations is available. High nitrite concentrations in ponds would not be anticipated given the level of prawn biomass at harvest. Levels of un-ionized ammonia, exceeding 0.1 mg/L (ppm), can be very detrimental in fish ponds. Concentrations of un-ionized ammonia as low as 0.26 mg/L (ppm) at a pH of 6.83 have been reported to kill 50% of the prawns in a population within 144 hours (Arm-

Table 3. Weight-dependent feeding rates for semi-intensive pond growout of *Macrobrachium rosenbergii*.

Mean wet weight (g)	Daily feeding rate (% of body weight)[a]
<5	0
5-15	7
15-25	5
>25	3

[a]As-fed weight of diet/wet biomass of prawns x 100

strong et al., 1978). Therefore, the occurrence of concentrations of un-ionized ammonia that are 0.1 mg/L (ppm) or higher must be avoided.

pH. A high pH can cause mortality directly by means of a toxic effect, and indirectly by providing a condition whereby a higher percentage of ammonia exists in the toxic un-ionized form. Although freshwater prawns have been raised in ponds with a pH range of 6.0 to 10.0 with no apparent adverse effect on survival, a pH between 6.5 and 9.5 is recommended. High pH values usually occur in water having a total alkalinity $\leq$ 50 mg/L (ppm) in association with a dense algal bloom. Adding lime to ponds that are constructed in acid soils can help minimize severe pH fluctuations that might occur after the pond is filled with water and stocked.

Two other management practices designed to treat or mitigate a problem of high pH are reducing the quantity of algae in the pond by periodic flushing (removing) of the top 30.5 cm (12 in) of surface water, or by provision of organic matter, such as corn grain or rice bran, over the surface area of the pond. The organic matter should be introduced gradually to achieve a rate of 13 kg/A (32 kg/ha) over a period of 2 weeks. The latter procedure must be accompanied by careful monitoring of oxygen levels, which may dramatically decrease due to a heavy oxygen demand caused by degradation of organic matter. If flushing is conducted, care must be exercised to ensure that the quality of the effluent meets the standards established by the appropriate state agency.

Under certain conditions, a dense growth of filamentous algae may occur in production ponds. Seine harvest cannot be effectively performed under these conditions. Such a situation can be potentially avoided by introducing herbivorous fish at low densities shortly after stocking of the prawns. Before using a chemical algicide to control algae growth in a freshwater prawn pond, perform a bioassay. Place a few prawns in several plastic buckets containing aerated pond water containing the algicide at the recommended level of application. Then, periodically observe the prawns over a period of at least 24 hours for mortality or for behavior suggesting stressful conditions.

Diseases

Disease has yet to be identified as a major problem affecting production of freshwater prawns, but as stocking rate and biomass per unit area increase, the potential for disease-related mortality increases. "Black spot," or "shell disease," is one disease that may be encountered. This disease is caused by bacteria that break down the outer shell (exoskeleton). Incidence is usually associated with physical damage and can be avoided by careful and minimal handling. This adverse condition of the shell (exoskeleton) is eliminated by shedding. At times, algae or insect eggs may be present on the shell. This condition is not a disease but is an indicator of low growth rates (low rate of shedding). Potential outbreaks of mortality during larval culture due to the proliferation of bacteria can be avoided or treated with the introduction of 1 mg/L (1 ppm) of oxolinic acid.

Harvesting

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 half prior to seining. Alternatively, ponds could be designed to have a large rectangular bar pit (ditch) deeper than the surrounding pond bottom where water would remain after draining and prawns would concentrate for seine harvest. Some prawns will remain after seine harvest and will have to be removed manually after complete draining. In the complete drain-down harvest procedure, prawns follow the receding water and eventually travel through a drain pipe into a collecting device generally located on the outside of the pond levee. Effective drain harvesting can only be accomplished if ponds have a smooth bottom and a slope that will ensure rapid and complete draining. Sufficient aeration should be provided to the water in the collection device or small collecting pond to avoid stress and possible mortality.

Selective harvest of large prawns by seining during a period of 4 to 6 weeks prior to final harvest has been recommended to increase total yield from a pond during a growing season. Selective harvesting is usually performed with a 2.54- to 5.1-cm (1- to 2-in) square mesh seine to remove the largest individuals from the pond. Selective harvest may also be accomplished with properly designed traps. Prawns have been trapped using a wide array of traditionally designed crayfish traps. Insufficient research has been performed to demonstrate conclusively that a selective harvest practice is more cost effective than a single bulk harvest at the end of the growing season. Selective harvest can potentially extend the duration of availability of the fresh or live product for the market.

During a complete drain down of a production pond, some of the prawns will become stranded in pools of water and these individuals will have to be manually harvested. A properly constructed pond consisting of a good slope from the shallow end toward the drain and a well compacted smooth bottom will maximize removal by seine and minimize stranding that could be a source of stress.

Polyculture and Intercropping

Culture of freshwater prawns in combination with fingerling catfish has been successfully demonstrated under small-scale experimental conditions and should be possible under large-scale conditions. Juvenile prawns should be stocked at a rate of 7,407-12,346/ha (3,000-5,000/A) prior to introduction of fry. Fry should be stocked at a density to ensure that they will pass through a 2.54-cm (1-inch) mesh seine used to harvest the prawns at the end of the growing season. Although polyculture of prawns and a mixed population of channel catfish has been successfully demonstrated, logisti-

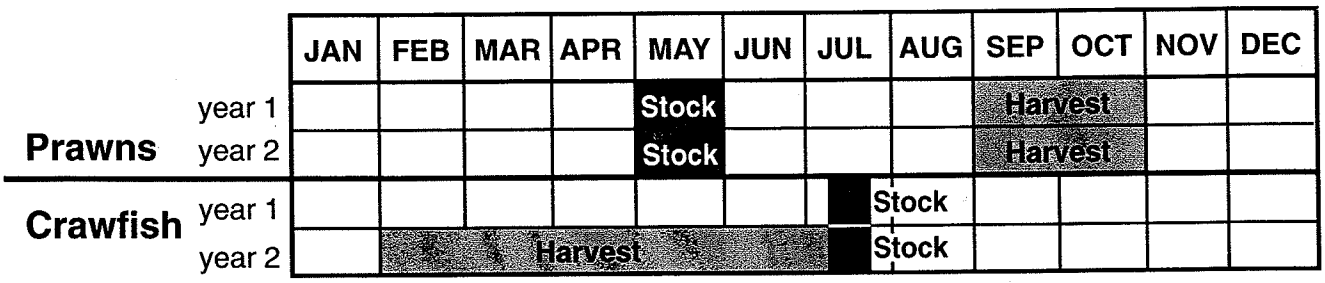

Figure 4. Stocking and harvest scheme for intercropping of the freshwater prawn, *Macrobrachium rosenbergii,* and the red swamp crayfish, *Procambarus clarkii.*

cal problems arising from efficient separation of the two crops are inherent in this management practice. Moreover, when harvest of prawns is imminent because of the occurrence of coldwater temperatures, catfish may not be in a condition to be harvested because of an "off flavor" characteristic. Polyculture of channel catfish and freshwater prawns may be best achieved through cage culture of the fish.

Recently, a scheme for intercropping of freshwater prawns and red swamp crayfish has been developed and evaluated (Figure 4). Intercropping is the culture of two species that are stocked at different times of the year with little, if any, overlap of their growth and harvest seasons. Intercropping provides for a number of benefits, including (1) minimizing competition for resources, (2) avoiding potential problems of species separation during or after harvest, and (3) spreading fixed costs of a production unit (pond) over an entire calendar year.

Adult mature crayfish are stocked at a rate of 225 kg/ha (200 lb/A) in late June or early July. Juvenile prawns are stocked at a density of 38,672/ha (16,000/A) in late May and harvested from late August through early October. In late February, seine- or trap-harvest of the crayfish commences and continues through late June/early July before stocking of new adult crayfish. Prawns are small enough to pass through the mesh of the seine (1.59 cm or 5/8 in) used to harvest crayfish during the May-June overlap period.

Processing and Marketing

Production levels and harvesting practices should match marketing strategies. Without this approach, financial loss due to lack of adequate storage (holding) facilities or price variability is inevitable. Marketing studies strongly suggest that a "heads off" product should be avoided and that a specific market niche for whole freshwater prawns needs to be identified and carefully developed. In order to establish year-round distribution of this seasonal product, freezing (preferably individually quick frozen, IQF) would be an attractive form of processing. Block frozen is an alternative method of processing for long-term distribution. Fresh on ice or live are often preferred forms for distribution and generally command the highest prices.

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 good aeration. Distribution of prawns on "shelves" stacked vertically within the water column assists in avoiding mortality caused by crowding and localized deterioration of water quality. Use of holding water with a comparatively cool temperature 20-22 °C (68-71.6 °F) will minimize incidence of water quality problems and injury caused by encounter by reducing the activity level of the prawns.

Economic Feasibility

Based upon a current feed cost of $227-$272/metric ton ($250-$300/ton), a seed cost of $60/1,000 juveniles, a 2.5 to 1 feed conversion ratio, expected mean yields of 1120 kg/ha (1,000 lb/A), and a pond bank selling price of $9.38/kg ($4.25/lb), the expected net return is $4,820-$6,025/ha ($2,000-$2,500/A). This estimated return does not include labor costs or other costs. Revenue and ultimately profit are also dependent upon the type of market that is being utilized. Some thorough economic evaluations that incorporate annual ownership and operating costs under different scenarios for a synthesized firm of 17.4 ha (43.0 A), having 4.15 ha (10.25 A) of water surface in production, are provided by Montanez et al. (1992).

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