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Small-Scale, Year-Round Shrimp Farming in Temperate Climates

By: *Andrew J. Ray*[1], *Robert Rode*[2]

Interest in indoor shrimp aquaculture as a means of producing high-quality, fresh, never-frozen marine shrimp in practically any location is growing.

Indoor shrimp production allows farmers to tap into niche markets where consumers are willing to pay a higher price for top-quality, locally grown food products. Nonetheless, people interested in shrimp farming should do substantial research before making an investment; risk can be minimized by starting small.

System Design

Buildings:

In temperate climates, the consistent environment of an insulated building facilitates faster growth rates in shrimp than greenhouses or ponds, even in the warmer months. The building should be ventilated to prevent buildup of carbon dioxide and excess moisture. Surfaces in the building should be protected against moisture. Since it contains salt, moisture generated in a shrimp farm is especially corrosive to metal and damaging to wood.

Tanks:

Swimming pools make inexpensive tanks, and they are a favorite choice for many small-scale farmers. Their long-term durability is uncertain since liners can leak and metal supports can rust. Pool liners should not contain algaecides or other chemicals as these can be toxic. Liners must be protected from abrasion or punctures and should be rinsed before use.

The normal water level in tanks should be about three feet. This depth allows adequate contact time for air bubbles moving through the water column. Pools should be covered with netting that has a mesh size small enough to prevent shrimp from escaping, but large enough to allow feed to pass through.

Aeration:

The simplest way to aerate the water is with a regenerative blower. Generally, 3 CFM (cubic feet per minute) of air is needed per pound of feed per day. For adequate pressure, make sure to calculate the depth of the water and add at least another 15% to account for resistance in air lines and diffusers.

A large diameter, thin-walled, metal cooling pipe is recommended between the blower outlet and the PVC airline piping (Fig. 1) to prevent damage from excessive heat. Valves should be installed so the amount of air to each diffuser can be adjusted, and diffusers should be evenly spaced on the tank bottom.

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Solids Filtration:

Particles in the water should remain in suspension. If solids accumulate on the bottom they can generate ammonia and may become anaerobic, producing hydrogen sulfide, which is very toxic to shrimp. Excessive solids in the water can lead to gill clogging, low DO, and bacterial infections. Solids filtration is best achieved through the use of both a foam fractionator to remove small particles and a settling chamber for larger particles. Store-bought fractionators can be cost-prohibitive but do-it-yourself (DIY) units can be just as effective (Figs. 2 and 3). Typically, the fractionator is plumbed separately so that the flow rate can be adjusted independently. Cone-bottom tanks work best as settling chambers, but a standard liquid storage drum is a suitable alternative (Figs. 4 and 5). The settling chamber should be about 1.25% of the volume of the shrimp tank it serves.

Figure 1. A regenerative blower with a cooling pipe. Two air filters prevent debris from entering the blower and should be examined regularly and cleaned if needed.

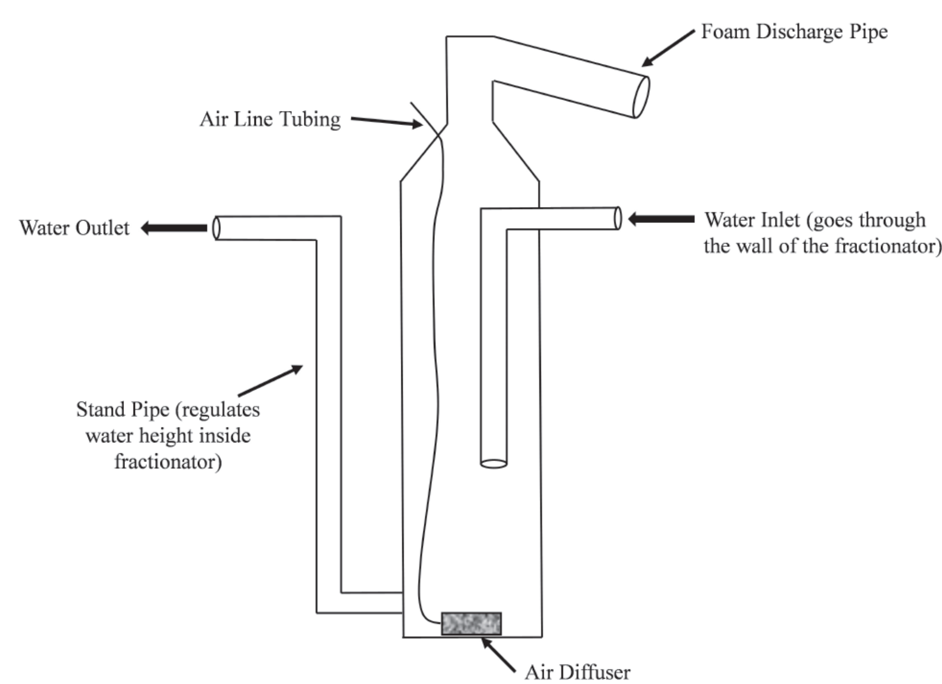

Figure 2. A diagram of a homemade foam fractionator. Inlet and outlet pipes go through the body via rubber gaskets or bulkheads. The outlet is a stand pipe; by turning it at the bulkhead, the water level inside the fractionator is adjusted.

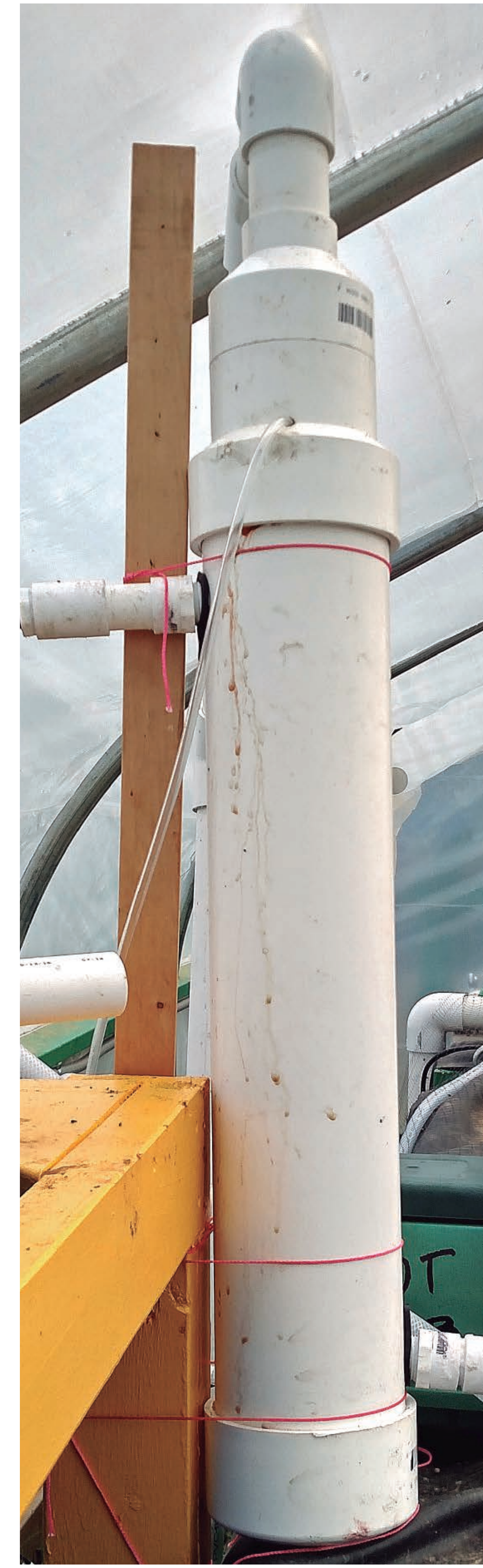

Figure 3. A picture of a homemade foam fractionator. A valve near the inlet is used to adjust the flow rate. A submersible fountain pump delivers water to this filter.

Sludge that forms in the settling chamber should be removed weekly. The most water-efficient way to remove the sludge is to pump the relatively clear water from the top of the chamber, allow the remaining water to settle for at least 30 minutes and then dump the remainder (the thick sludge) through a bottom drain. Fractionators and their diffusers also need to be cleaned and adjusted periodically.

To measure solids, one liter of water from the shrimp tank is poured into an Imhoff cone and allowed to settle for one hour. Settleable solids should be kept below 15 ml/L, and in systems with an external biofilter, they should be kept as low as possible. With experience, managers can consider the clarity of the water as another indicator of solids levels.

Biofiltration:

Operating an external biofilter is the simplest way to resolve the issue of ammonia accumulation although the "biofloc" approach is an alternative that some farmers use. Due to the relative complexity of the biofloc approach, it has been difficult for new aquaculture farmers to implement, therefore the focus of this discussion is on external biofiltration to reduce risk.

The purpose of the biofilter is to harbor a community of nitrifying bacteria that convert ammonia to

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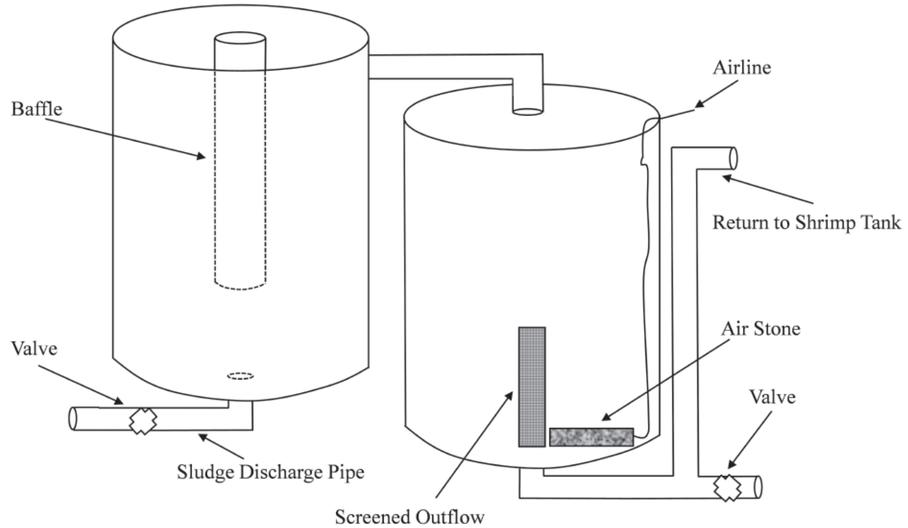

Figure 4. A diagram of a simple settling chamber and biofilter combination. Water enters the settling chamber baffle (a larger diameter pipe or corrugated pipe) which causes velocity to slow and solids to settle. The water then flows through the biofilter and back to the shrimp tank.

Figure 5. A simple settling chamber and a biofilter. The settling chamber is higher to allow water to travel to the biofilter via gravity. The filters are supported by concrete blocks. Note the protected surfaces in the room and covered tank.

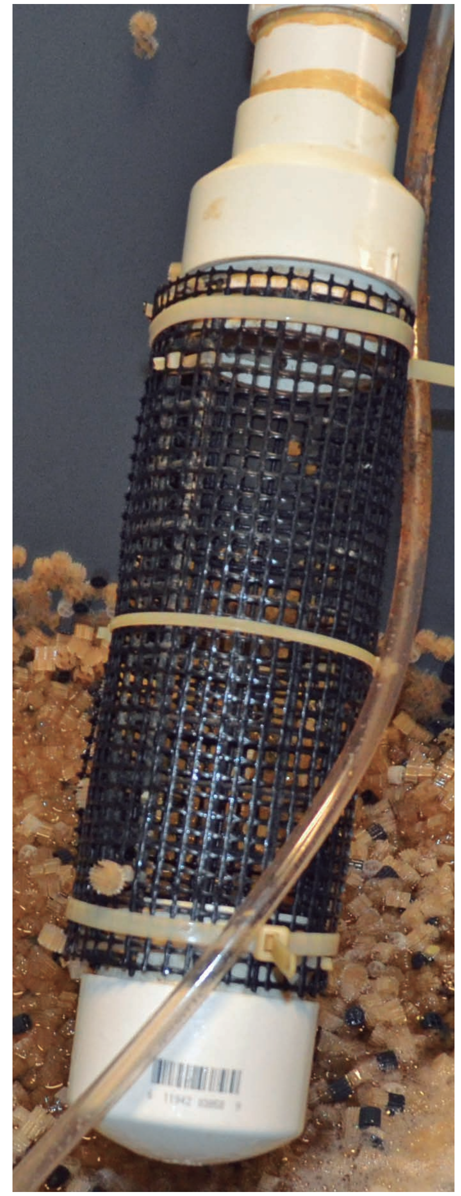

Figure 6. A screened outflow in a biofilter. This can be placed on the tank bottom to allow water to pass through but not biomedia. Also note the small biomedia, most of which has turned brown, indicating a population of helpful bacteria is established.

nitrite (NO) and subsequently convert nitrite to nitrate (NO_3). Both ammonia and nitrite are toxic at relatively low concentrations (Table 1) but as long as the nitrifying bacteria are provided the correct environment, they should not accumulate.

An external biofilter can be constructed from a 50-gallon storage drum (Figs. 3 and 4). The biofilter should contain specially designed plastic media (often referred to as biomedia), which provide surface area for bacterial colonization. Established media will have a brown slime growing on it. The media should be kept gently moving and aerated by placing a 12-inch diffuser on the bottom of the filter. A diffuser of this size delivers about 1 CFM of air, which is appropriate for a 50-gallon drum biofilter. If water mixing is too aggressive the bacteria may be dislodged from the biomedia. A screened outflow pipe should be used (Fig. 6). Biofilters should contain 1 cubic foot of biomedia for every 0.75 pounds of feed fed per day. Biomedia typically has a surface area of approximately 250-300 ft^2/ft^3, but manufacturers' specifications may differ. Biomedia should take up 50-70% of the biofilter volume. Overfilling prevents media from moving in the water.

Solids that accumulate on the bottom of biofilters should be removed weekly. If the biomedia appears to become clogged, it should be gently agitated to dislodge some bacterial biomass. The entire volume of the shrimp tank should pass through the filters at least three times daily.

Water Quality Factors

Temperature:

Maintaining a temperature of 28.5°C will result in optimal growth. When shrimp are being handled or if there are problems with water quality, the temperature can be lowered gradually to reduce stress. A temperature of about 26°C will

> **The purpose of the biofilter** is to harbor a community of nitrifying bacteria that convert ammonia to nitrite (NO_2) and subsequently convert nitrite to nitrate (NO_3).

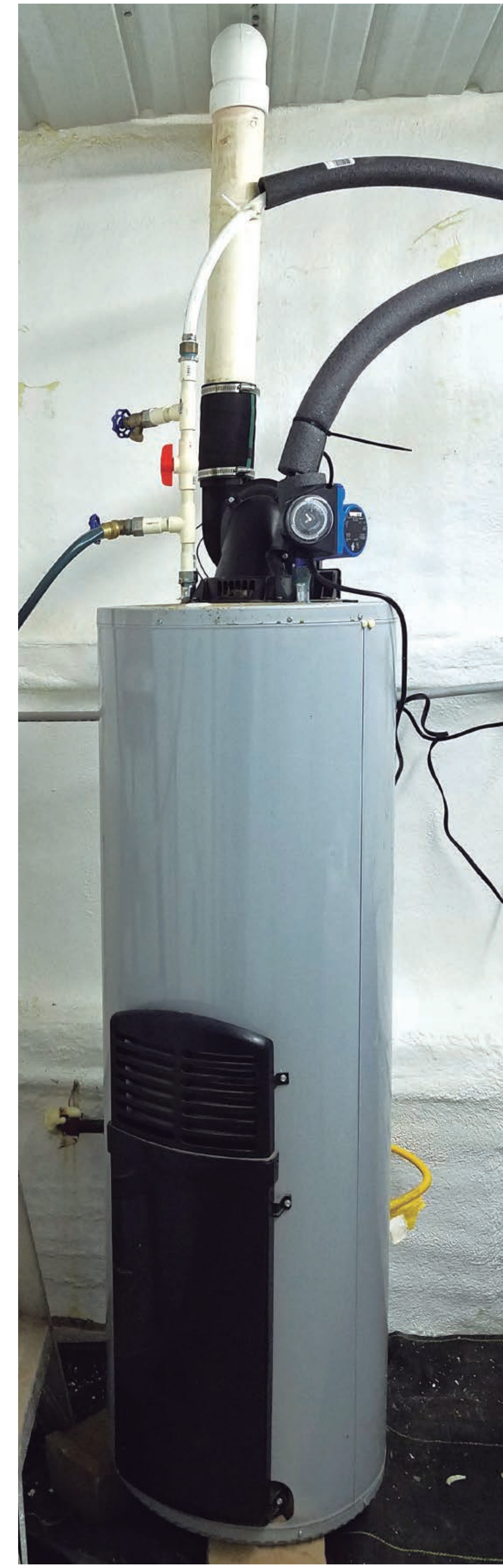

Figure 7. A household water heater with a circulation pump which also has a timer so that it can be operated for a set period of time each day. The water travels to coils of PEX pipe in each shrimp tank, then back to the water heater.

reduce the amount of stress considerably. Feed rate should likewise be lowered at this time.

An economical approach to temperature control for small-scale operations is to use a water heater connected to cross-linked polyethylene (PEX) tubing with a circulation pump that circulates fresh, heated tap water through the tubing (Fig. 7). A coil of PEX tubing placed inside each shrimp tank will radiate heat to the water (Fig. 8). Temperature can be regulated by controlling water flow at each tank with a valve. During hot weather, the room should be well-ventilated to allow plenty of cooling capacity and bring necessary fresh air into the room.

Dissolved Oxygen (DO):

DO is the most critical factor in intensive shrimp farming. DO should be maintained above 5 mg/L; lower concentrations are acceptable for short periods of time, but levels below 3.5 mg/L are critical. It is important to note that temperature, feed rate, CO_2 accumulation in the building, stocking density, solids concentration, and the addition of sugar all affect DO concentration negatively.

Aeration must be maintained at all times in shrimp tanks. Short periods with no aeration in the biofilter are fine if the media remains wet. As little as 15 minutes without aeration can cause shrimp mortality. It is important to have backup blowers and an emergency generator with a power transfer switch to operate blowers and other equipment during power outages. Another good investment is one or two large tanks of pressurized oxygen that can be connected to a regulator and diffuser(s) to deliver pure oxygen to tanks if needed.

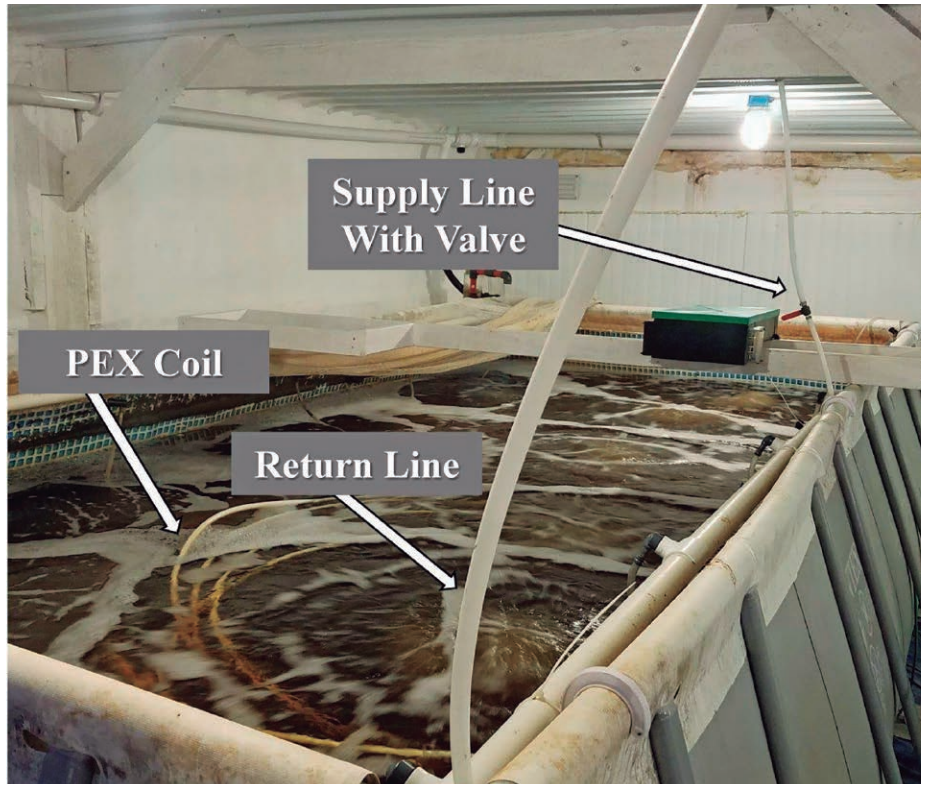

Figure 8. A shrimp tank with PEX piping that carries hot water to heat the tank. A valve controls the flow rate of water. In this case the coil of pipe is loose in the water; however, it may also be bundled together to keep the coil more contained.

Table 1

The most important water quality parameters. Temperature, DO, and pH should be measured at least daily and must be measured in the tank. In other words, water should not be removed and tested elsewhere. Salinity, ammonia, nitrite, and solids should be measured at least weekly. Nitrate should be measured every other week. Parameters should be measured more frequently if problems are detected. Refer to Figs. 9, 10, and 11 for examples of water quality testing supplies.

Parameter	Measurement	Ideal	Danger
Temperature	Probe or Thermometer	28.5°C	Under 18, Over 32
DO	Probe	Over 5.0 mg/L	Under 3.5
pH	Probe	7.5 - 8.0	Under 7.0, Over 8.5
Salinity	Probe or Refractometer	10 - 20 ppt	under 5
Ammonia	Color Change Test	Under 0.2 mg/L	Over 1.0
Nitrite	Color Change Test	Under 1.0 mg/L	Over 5.0
Nitrate	Color Change Test	Under 100 mg/L	Over 250 mg/L
Solids	Settleable Solids	Under 15 ml/L	Over 25 ml/L
	Turbidity	Under 30 NTU	Over 80 NTU

Table 2

An example feed sheet for the nursery phase. This is only one example of how a feed sheet may be structured.

Day	Stage	Weight	Survival	Orig. #	# Shrimp	Biomass (g)	% Biomass	Feed/Day (g)	Feed Size (µm)
8	PL15	0.01	98.26	30000	29479	295	0.15	44.2	50% 400-600, 50% <400
9	PL16	0.02	98.02	30000	29405	588	0.15	88.2	60% 400-600, 40% <400
10	PL17	0.03	97.77	30000	29332	880	0.14	123.2	70% 400-600, 30% <400
11	PL18	0.04	97.53	30000	29258	1170	0.13	152.1	80% 400-600, 20% <400
12	PL19	0.05	97.28	30000	29185	1459	0.13	189.7	90% 400-600, 10% <400
13	PL20	0.06	97.04	30000	29112	1747	0.14	244.5	90% 400-600, 10% 600-850
14	PL21	0.07	96.80	30000	29039	2033	0.135	274.4	80% 400-600, 20% 600-850
15	PL22	0.08	96.56	30000	28967	2317	0.135	312.8	70% 400-600, 30% 600-850
16	PL23	0.09	96.31	30000	28894	2601	0.135	351.1	60% 400-600, 40% 600-850
17	PL24	0.1	96.07	30000	28822	2882	0.134	386.2	50% 400-600, 50% 600-850

When shrimp are being handled or if there are problems with water quality, the temperature can be lowered gradually to reduce stress.

Figure 9. A multi-parameter water quality instrument. This unit measures temperature, pH, DO, salinity, conductivity, and barometric pressure. This type of device is expensive but it measures some of the most critical life-sustaining parameters.

Table 3

Example of a grow-out phase feed sheet.

Day	Survival	# Shrimp	Ind. Wt.	Biomass (g)	FCR:1	Growth/wk	Feed/shrimp	Feed (g)/wk
1	1.000	30000	1.270	38100	1.3	1.0	1.300	39000
2	0.900	27000	1.413	38147	1.3	1.0	1.300	35100
3	0.899	26973	1.556	41962	1.3	1.0	1.300	35065
4	0.898	26946	1.699	45770	1.3	1.0	1.300	35030
5	0.897	26919	1.841	49570	1.3	1.0	1.300	34995
6	0.896	26892	1.984	53362	1.3	1.0	1.300	34960
7	0.896	26865	2.127	57146	1.3	1.0	1.300	34925
8	0.895	26838	2.270	60923	1.3	1.0	1.300	34890
9	0.894	26812	2.413	64692	1.3	1.0	1.300	34855
10	0.893	26785	2.556	68454	1.3	1.0	1.300	34820

pH

The pH should be maintained at 7.5 - 8.0 to ensure that shrimp are healthy and have firm exoskeletons. CO_2 produced by shrimp, bacteria and the nitrification process decreases pH. Sodium bicarbonate (baking soda) is widely used to buffer against decreasing pH. Depending on building ventilation and solids concentration, baking soda may need to be added at a rate of up to 50% of the weight of the feed. Monitor pH and add incrementally larger amounts of baking soda until the pH is stable.

Salinity:

Salinity should be maintained at 15-20 parts per thousand (ppt). Lower salinity levels can be used but ammonia, nitrite, and nitrate are generally more toxic at lower salinity. Most hatcheries ship young shrimp in full-strength seawater (about 35 ppt); but they can be slowly adjusted to lower salinity over one week. Recent research conducted at Kentucky State University (KSU) suggests that home-made salt mixtures may be just as effective as off-the-shelf complete sea salt formulations and 60% less expensive.

Ammonia and Nitrite:

Ammonia is the most toxic nitrogen-based compound and should be maintained at less than 0.2 mg/L

Figure 10. A pH and temperature meter. This type of meter is much less expensive than a multi-parameter style unit. Similar instruments can measure DO and salinity.

Figure 11. A common type of test for parameters such as ammonia, nitrite, and nitrate. This particular test measures nitrite. Drops of a chemical are added to the water sample and the resulting water color is compared to the chart. Water should be filtered to remove solids if possible before these tests are conducted. If concentrations are out of range, dilutions should be made with deionized water; the results of a 50/50% dilution would need to be multiplied by two for instance.

while nitrite should be maintained at less than 1 mg/L although short periods of elevated concentrations should not pose much risk. Lower salinity makes these compounds more toxic. Higher temperature and pH both make ammonia more toxic.

If ammonia or nitrite reach high concentrations, feeding rate can be reduced, lowering the amount of nitrogen entering the system. Slowly reducing the water temperature (approximately 5°C per day maximum) will lower the feed consumption rate and reduce ammonia toxicity and overall stress. In some cases, system water can be exchanged with clean water; however, this is expensive and less effective than solving the cause of the problems.

Adding sugar stimulates bacteria to take up nitrogen compounds, reducing ammonia and nitrite. Household white sucrose can be added at up to 50% of the weight of feed or slightly more to quickly drive down ammonia and nitrite. Using sugar will reduce the DO concentration and increase the amount of solids in the water. A small amount of sugar, around 100 grams (3.5 oz.) for a 4,000-gallon pool, should be added at first. This amount can be increased incrementally as needed. Sugar should not be added within an hour of feeding since feed also lowers DO.

Nitrate:
Nitrate is the end result of the nitrification process, accumulating as the biofilter works. It is much less toxic than ammonia or nitrite, but may start to depress growth at 250 mg/L, depending on salinity. Denitrification can reduce nitrate levels by essentially performing nitrification in reverse. In an oxygen limited environment, nitrate can be converted to harmless nitrogen gas. However, denitrification has potentially serious risks, including production of hydrogen sulfide. Water should ideally be moved to a separate container for denitrification. A 50-gallon drum filled with biomedia without aeration is suitable. A small submersible pump may be used to stir the biomedia without introducing air or disturbing the water surface. Flow-through rate should be limited so that the bacteria on the biomedia can maintain the DO below 1 mg/L.

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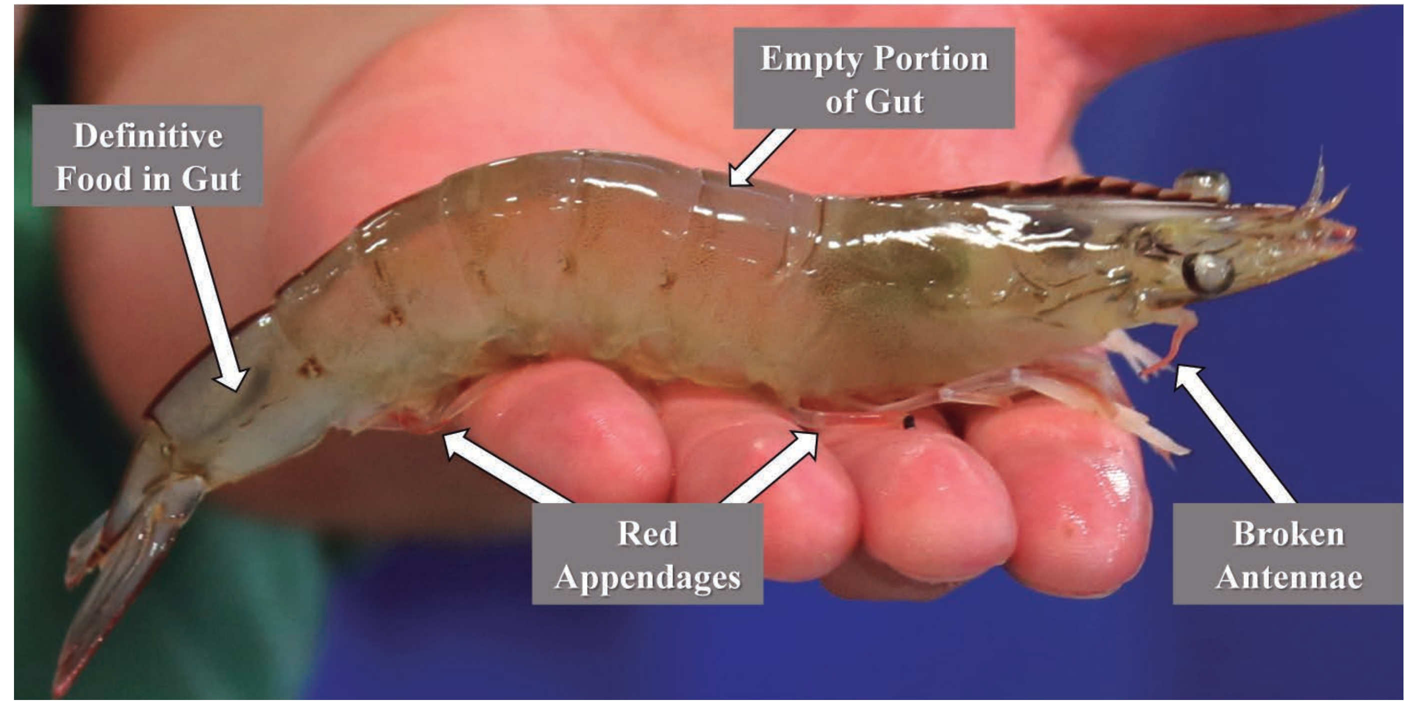

Figure 12. This shrimp has a partially empty gut, indicating the animal is slightly underfed. Broken antennae can be the result of high density culture. Red appendages can be a sign of bacterial activity; solids concentration may be high in the culture tank. The exoskeleton is firm though and the overall appearance is acceptable for harvest and sale.

Feeding and Health
Indoor shrimp farming is commonly conducted in nursery and grow-out phases. An appropriate starting density for the nursery phase is 2,500 shrimp/m^3 or about 11.4 shrimp/gallon. Higher densities can be used as managers become more familiar with production systems. During the nursery phase, shrimp are normally fed based on percentage of biomass. The initial feeding rate can be as high as 15% of the shrimp biomass per day. Through the nursery phase, this should be gradually reduced to about 3% biomass per day (Table 2). Depending on density and management, shrimp will be in the nursery phase for about 40 days before producing a one-gram animal.

Providing some freshly hatched Artemia (about 1,800/gallon/day) for the first week after the shrimp are received will improve survival. Through the initial nursery phase, shrimp should be provided a high-quality crumbled feed with about 50% protein. Transition them to larger crumble sizes as they grow, and to a pelleted diet with approximately 35% protein in the late nursery and grow-out phases.

During grow-out, feeding is based on estimates of feed conversion rate (FCR), survival, and growth rate (Table 3). If the FCR is assumed to be 1.5: 1, growth rate is 1.5 g/week, and the tank contains 4,000 shrimp, the calculation is 1.5 x 1.5 x 4,000 which equals 9,000 grams per week. Feed should be applied

Figure 13. Sales of shrimp at a farmers' market. Direct sales to consumers are typically the most lucrative way to distribute shrimp.

frequently and automatic feeders are often used. A farmer may check water quality parameters and feed 10% of the calculated feed ration by hand in the morning and place 30% of the daily feed ration on a 12-hour belt feeder. The farmer may repeat this process in the evening, adding more feed for the nighttime hours.

> **Ammonia is the most toxic** nitrogen-based compound and should be maintained at less than 0.2 mg/L while nitrite should be maintained at less than 1 mg/L although short periods of elevated concentrations should not pose much risk.

Feed calculations are estimates. Managers must monitor feed consumption periodically using a net with appropriately sized mesh to collect uneaten feed. All food should be consumed between feedings. Shrimp should normally have a full hind gut, indicating they are eating and in good health (Fig. 12). An occasional shrimp with a soft exoskeleton is not concerning, but finding multiple soft shrimp indicates that the tank may be stressed. The rostrum should also generally be intact and there should not be many lesions or scars on the shrimp.

Economic Considerations

The importance of key economic factors varies considerably between farms. One of the major capital costs can be the building housing the operation. A simple pole barn structure with spray foam insulation on the interior makes a practical space for indoor shrimp production. Packed gravel makes an adequate floor, although sand may be needed under each tank to protect pool liners. Other major capital investments include a generator, heating system, electrical circuitry, pools, air blowers, water quality meters, air diffusers, biofilter media, feeders, nets and netting, and plumbing supplies.

Major operating and variable costs include feeds, labor, post larvae, energy, artificial salt, water, and transportation costs. Overhead may include maintenance, insurance, and professional services (such as consulting fees). It may be possible to reduce some of these costs.

Marketing Shrimp

At a stocking density of 250 shrimp/m^3 in the grow-out phase, farmers with good management can expect to have approximately 80% survival. If shrimp are grown to an average

Figure 14. Shrimp packaged in a small onion sack-style bag. This makes them easy to retrieve when buried in ice. Shrimp should be chilled in ice water for about 10 minutes immediately after harvest to euthanize them and cool the meat temperature, then stored on drained ice.

of 24 grams, total harvest can be 4 - 5 kg shrimp/m^3. With practice, farmers should be able to consistently attain 6 kg/m^3. Higher harvest rates may be possible, but are not generally repeatable.

Shrimp is one of the few products that can command a higher price for greater unit weights. Most farmers find it worthwhile to grow a larger animal and 24 grams is the routine target weight at KSU. To produce larger shrimp, the length of the grow-out phase will need to be extended. As biomass in a tank increases, the oxygen demand will also increase. Partial tank harvests can be implemented to reduce biomass, but care should be taken to limit stress on the remaining animals.

Most farmers target niche markets and attempt to supply shrimp directly to the consumer whole (usually on-ice) to optimize the sale price (Fig. 13). Onion sack-style bags are useful for packaging shrimp, as the animals can be buried in ice and easily recovered (Fig. 14). Selling to restaurants or distributors usually reduces the sale price and processing the animals adds to certification issues and labor costs. Check with local health department officials before freezing or de-heading shrimp since most areas have specific guidelines that must be followed.

[1] Assistant Professor of Aquaculture Production, Kentucky State University College of Agriculture, Communities, and the Environment, School of Aquaculture and Aquatic Sciences.
[2] Manager, Aquaculture Research Lab, Purdue University.
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