Southern Regional Aquaculture Center

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Indoor Marine Shrimp Farming

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The Pacific white shrimp or white-leg shrimp (*Litopenaeus vannamei*) is especially well-suited to inland, indoor aquaculture. This is the most commonly farmed species throughout the world and has been in captive breeding programs for decades. As a result, the shrimp has traits such as fast growth rate, disease resistance, and an ability to tolerate high-density culture. It is the most common shrimp found in U.S. supermarkets and restaurants, and is therefore a familiar product among consumers.

There are multiple ways to grow Pacific white shrimp, but this paper focuses on intensive, indoor production systems. Such systems can be used to produce high-quality fresh, never-frozen, shrimp practically anywhere and anytime. The systems can be used to serve markets where fresh shrimp is a rare commodity, or where there are shortages or inconsistencies in supply. In many regions head-on, fresh shrimp is difficult to find, and selling such a unique product may open high-end marketing opportunities while reducing overall production costs associated with processing.

Most developed countries, such as the United States, import significant numbers of shrimp which are generally sold at low prices. The comparatively high cost of producing shrimp indoors may make it difficult to compete against imported shrimp, thus many indoor farms target niche markets, primarily in and around urban areas. Due to the size of niche markets in the United States there are a number of small farms around the country. These operations obtain post larvae shrimp from hatcheries, and complete the remainder of the production cycle indoors. Many are tapping into consumer markets that value locally grown, sustainable, and healthy food products. Being indoors provides control over production, eliminating most environmental interactions, and facilitating consistent, year-round production.

To facilitate indoor production away from the coast, recirculating aquaculture systems (RAS) must be used. The term recirculating refers to very low water use; below 1 percent exchange per day and often much lower than that. This allows water, salt, and heat to be conserved which are important for growing this warm-water (optimal growth at 83°F or 28.5°C) marine species. Two types of RAS are biofloc (BF) and external biofilter-style (EB) systems. Although many variations of these techniques exist, the fundamental difference between them is that biofiltration (the mitigation of nitrogen compounds, especially ammonia) is performed internally in BF and externally in EB systems. Microbes, primarily bacteria, perform biofiltration; in BF those bacteria are in the water with shrimp, and in EB the bacteria are largely contained in a separate filter.

Building considerations

Types of buildings

A variety of spaces can be used to grow shrimp, including custom-built structures, re-purposed urban facilities such as warehouses, or re-purposed agriculture infrastructure such as barns and greenhouses. Some factors to consider when choosing a facility are temperature and humidity control, effects of water and salt on building materials, electricity availability, harvest strategy, waste discharge strategy, local permitting, and cost.

In tropical locations, greenhouses may be used to grow shrimp year-round. Depending on energy costs, well-insulated greenhouses that are heated part of the year may be used for year-round production in cooler climates. Greenhouses can be relatively inexpensive

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and allow solar heating during the day, but the amount of solar heat depends on location and weather patterns. Temperature and light fluctuations are common in greenhouse systems, which lead to slower growth rates in shrimp. To maximize control, biosecurity, and consistency of the systems, and to facilitate cool or cold weather farming, insulated spaces can be used to grow shrimp.

Heating and ventilation

Ventilation is important because of the buildup of moisture and carbon dioxide (CO_2) in a sealed space. Moisture adhering to surfaces can promote the growth of mold, which can have human health implications. If mold-containing water drips into shrimp tanks, it may also harm the animals. Carbon dioxide is produced by the shrimp as well as bacteria in the water and can be unhealthy for workers. Carbon dioxide (CO_2) in the air can also prevent CO_2 from escaping from the water, which will cause a buildup in water, lower pH, and necessitate greater buffer (carbonate) inputs. Fresh air can be brought in through the system used to aerate water in the shrimp tank, although a way to control the amount of outside air versus interior recycled air should be considered for the sake of temperature control. If an air blower is used, the temperature of the blown air will be slightly higher than the surrounding air because it is under increased pressure. However, the added heat is not enough to increase water temperature substantially. No matter how fresh air is introduced, interior air should be exhausted at a low point in the room to limit the amount of heat that is removed and because CO_2 is slightly heavier than air, it will tend to sink.

If only the water is heated and not air in the room, some condensation may occur on surfaces. Heating the air, as well as the water, reduces this condensation. Increasing the rate of fresh air exchange in the room will also reduce humidity. Some combination of these approaches may be warranted depending on the outside temperature, and heating the fresh air as it enters the room may be a useful option.

The most practical and cost-effective way to heat production systems is usually with a boiler, although some farmers use a household water heater. Clean freshwater is heated to a temperature considerably warmer than the intended tank temperature. This hot water does not contact the tank water, but is pumped through heat exchangers in the shrimp tanks. The exchanger material can be titanium, which exchanges heat efficiently, but is expensive; another commonly used material is cross-linked polyethylene (PEX) pipe which is easily bendable to allow a sufficiently large coil to be made to transfer heat to the tank. The coil is submerged in the culture tank and water in the tank must move around the exchanger coil to maximize contact.

Lighting

Indoor shrimp systems without a natural light source may benefit from the installation of artificial grow lights above the tanks. While additional research is needed on this topic, consideration should be given to lighting that facilitates a safe work environment. In addition, lights should be turned on and off gradually (such as with a dimmer switch). Abrupt changes in lighting will make shrimp jump which, even if they do not jump out of the tank, can cause injuries to the animals. Bruises and lesions make shrimp visually unappealing and can lead to potentially lethal infections.

Production systems

Tanks

Tanks for indoor shrimp production can come in many materials and a few different shapes. In some locations, a simple pond can be created by digging into the ground and placing a liner into the hole. Depending on the soil type, support structures may be required to prevent the hole from collapsing when there is no water in it. For intensive shrimp production, dirt bottom ponds are not recommended, as the soil microbiota can add substantially to the oxygen demand of the water, it is difficult to prevent sludge from accumulating on soil, and it is difficult to keep the water adequately mixed without disturbing the soil.

Wood-framed tanks are also a simple, and relatively low-cost option. Such structures can be partially buried to add rigidity, or built above ground (Fig. 1). High-density polyethylene (HDPE) and fiberglass (Fig. 2) are common tank materials. Although the cost is higher for these materials, they are durable and have relatively long useful life spans and typically do not require liners. The most durable material commonly used for tank construction is concrete (Fig. 3), which is typically reinforced with steel rebar. Either a liner or an epoxy coating is needed for concrete tanks, and it is difficult to make plumbing or other configuration changes if needed at a later date.

Small-scale farmers often use store-bought, above-ground swimming pools as tanks (Fig. 4). Swimming pools are usually the least expensive, readily available option for indoor shrimp farming, and a practical way to explore this business at the lowest initial investment. However, pool liners can be thin and some may include herbicides, fungicides, or other chemicals. These chemicals can be detrimental to shrimp or the microbial communities important for indoor aquaculture. Trusted liners should be used and should always be rinsed thoroughly before use. Additionally, some swimming pools have metal frames which may corrode. Overall, a tank type should be chosen that is strong and not prone to leaks. The weight of water is substantial and moving water makes tank stress even more profound.

Round tanks are common, largely because they are strong without external supports. Shrimp do just as well in rectangular tanks as in round tanks and rectangular tanks fit into most buildings better. In addition, rectangular tanks can increase the overall water-holding capacity of a

Figure 1. A wood-framed tank made from 2 × 6 inch boards lined with plywood, a layer of insulation, and a 45 mil rubber liner. Metal cables on the top and bottom hold the walls together, and sand on the bottom keeps the liner off the cables. This shrimp tank is in an unheated high tunnel-style greenhouse.

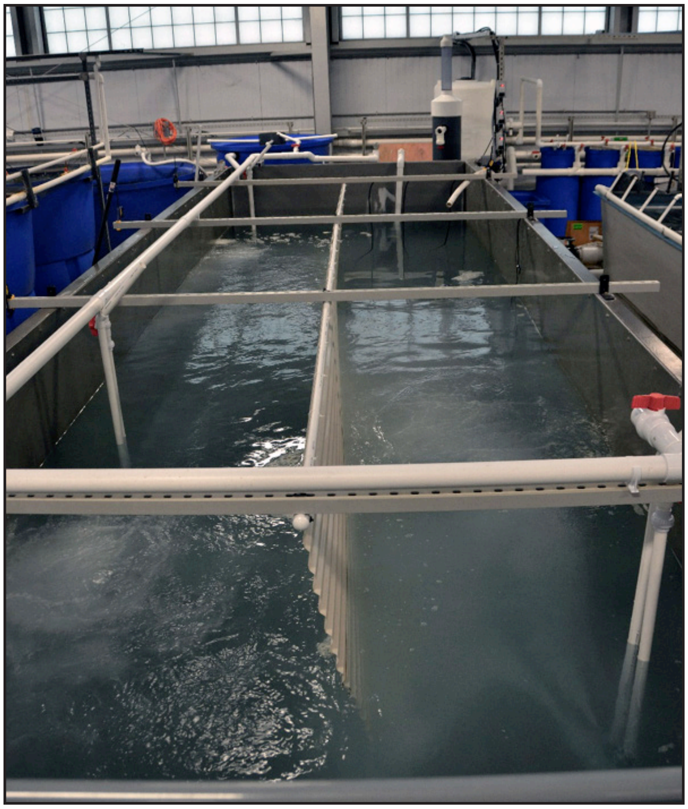

Figure 2. A rectangular fiberglass tank with a central divider. Water is pumped around the divider using a pump-driven aeration system with three Venturi-style nozzles.

Figure 3. A concrete tank with a reinforced polyethylene liner. Wooden slats are removed from a portion of the end wall to quickly harvest shrimp into a net. Water is diverted to a temporary storage area and the net is hoisted up and rolled along an I-beam to a shrimp sorting station.

Figure 4. Swimming pools being used as shrimp tanks in an indoor, insulated facility. The blue drums are filters, netting prevents shrimp from jumping out of the tanks, and blown air is delivered to diffusers through the PVC piping.

building compared to round tanks. A rectangular tank with rounded corners or D-shaped ends is ideal to minimize solids settling in the corners, and maximize the use of space. If a central divider is added, water can be pumped around it, which is an effective means of keeping the water mixed well (Fig. 2). Rectangular tanks can be susceptible to structural failure, usually on the longest walls where water pressure is greatest. Care should be taken to ensure the tanks are properly supported. Coated steel cables across the top and bottom of the tanks or triangular external supports outside the tank base are two ways to facilitate adequate support.

Aeration

Two primary styles of aeration are used in indoor shrimp farming: blown aeration or pump-driven aeration. Surface aerators, such as paddlewheels or fountain pumps, are not commonly used indoors due to excessive splashing and general inefficiencies in aerating smaller tanks.

Blown air is usually delivered by a regenerative blower. Blower manufacturers and distributors should be able to provide blower curves which illustrate the amount of air provided; usually in cubic feet per minute—CFM (liters per minute–LPM). They should also be able to recommend the amount of air needed given a specific application. Care should be taken to ensure the proper amount of air is delivered into the water and the appropriate pressure is provided to overcome the resistance of water depth and the pipe used to carry the air. Enough air must be provided to satisfy the respiration rates of the shrimp and the bacteria in the water, but if too much back-pressure builds it will damage the blower.

Blown air should be delivered through a diffuser. Ceramic diffusers are effective, commonly used, come in many sizes and shapes, and are generally rather durable. However, these diffusers need to be cleaned periodically and can be expensive. Diffuser hoses can be cut to nearly any length and bent to conform to certain shapes. Rubber-faced, disk diffusers have a rubber membrane with small holes for the air to escape. These diffusers can deliver large volumes of air and are cleaned when the rubber flexes. Blown air can be used to create air lifts to introduce some horizontal movement to the air and surrounding water or they can be used to move water to filters. Air lifts are created by surrounding a diffuser (typically a ceramic diffuser) with a pipe or by placing a deflector above the diffuser.

Well-designed, pump-driven systems move water horizontally while providing ample aeration. Pump-driven aeration systems typically incorporate a high-pressure pump that moves water through Venturi-style nozzles. The nozzles have a constricted section that is much narrower than the pipe around it that creates a low-pressure zone which pulls air in. Other, similar types of nozzles draw air in after the narrow section. If the nozzle is located below the water, then a pipe or tube (sometimes called a snorkel) connects the air intake zone to the air above the water. Inside such a nozzle, air is rapidly forced into the water, which creates very small air bubbles and effectively aerates the water. The fact that a high-pressure pump is required limits how much these systems can be scaled down and these systems are best used to aerate one individual tank rather than multiple tanks.

If a biofloc approach is used, the oxygen demand of the system is much greater than a system with lower solids levels. Shrimp respiration rate increases as shrimp biomass grows, and at times, biofloc can consume more oxygen than the shrimp (Fig. 5). The respiration rate of both shrimp and biofloc (even in lower solids level systems) is driven by feed input, and if carbohydrates are added, this further increases oxygen demand. As a general rule, 3 CFM (85 LPM) of air is needed per pound (450 g) of daily feed added in low solids system. This should be increased somewhat if using the biofloc approach, and managing solids levels is a key factor in oxygen demand.

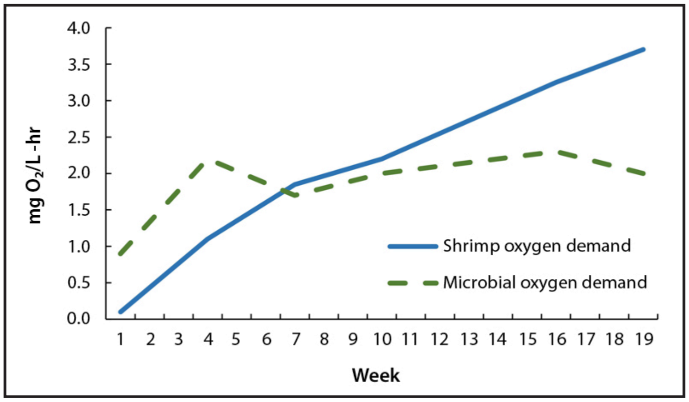

Figure 5. A graph illustrating the oxygen demand of shrimp and the bacteria in a biofloc system over time. As shrimp grow, they consume more oxygen. However, the microbial (bacterial) oxygen demand is always substantial.

Filtration

Two major components must be addressed with regard to managing water quality on a daily basis: the accumulation of solids and nitrogen compounds. Solids are typically composed of pieces of uneaten feed, feces, bacteria, zooplankton, algae, and other mostly organic matter. The primary nitrogen compounds of concern are ammonia (excreted by the animals) and nitrite (the result of oxidized ammonia); both of which are toxic. Most indoor shrimp facilities cannot exchange much water due to the cost of artificial salts and regulatory constraints. Therefore, solids should be removed with as little water loss as possible and managers are reliant on microbial processes to remove or transform ammonia and nitrite.

In BF systems solids are allowed to accumulate, although the concentration is regulated. The solids, referred to as biofloc particles, contain most of the microbes that process ammonia and nitrite (see SRAC Publication No. 4503, *Biofloc Production Systems for Aquaculture*). These particles may also provide substantial supplemental nutrition to the shrimp, thereby reducing feed usage. Biofloc systems may be more susceptible to rapid changes in water quality than biofilter-RAS and managing them properly takes a good understanding of the interactions between water quality and the microbial community. Biofloc systems do not require an external biofilter, which reduces the startup costs and the system footprint. Generally, biofloc systems are more biologically complex than EB systems.

In an EB system, an external biofilter is added to indoor shrimp systems to make water quality more stable. This is especially important for beginning farmers who may not fully understand the nuances of the chemistry and ecology involved with a biofloc system. Although clear water is not necessary for shrimp production in EB systems, lower solids levels should be maintained to help prevent bacterial blooms and shifts in water quality. An external biofilter can be made using a cylindrical container filled about half full with small, cylindrical plastic biomedia (see SRAC Publication No. 453, *Recirculating Aquaculture Tank Production Systems*). These biomedia are usually about ⅜ inch (1 cm) long with ridges to provide extra surface area for bacteria to adhere to. Water should flow through the filter, usually into the top and out of the bottom to maximize contact time between water and media. Since the bacteria consume oxygen and the media must be mixed to prevent clogging and maximize contact with water, aeration should be provided to oxygenate and mix the media.

With either biological filtration approach, the concentration of solids in the water must be regulated. Excess solids can cause gill clogging, lower DO concentrations, and contribute to bacterial infections. Two common filters used to manage solids are settling chambers and foam fractionators. Designs vary, but using a cone bottomed tank as a settling chamber makes it easier to drain the settled material. Water is pumped or airlifted to the settling chamber where it enters a large-diameter pipe suspended vertically to slow velocity, which allows suspended particles to settle out of the water (Fig. 6). Foam fractionators operate on the premise of passing small bubbles through a narrow column of water; the bubbles attract solids and collect at the top of the column as foam which is then discharged. Fractionators can be made using blown air with a counter-current flow through the water column, or a pump-driven nozzle system as described above (Fig. 7).

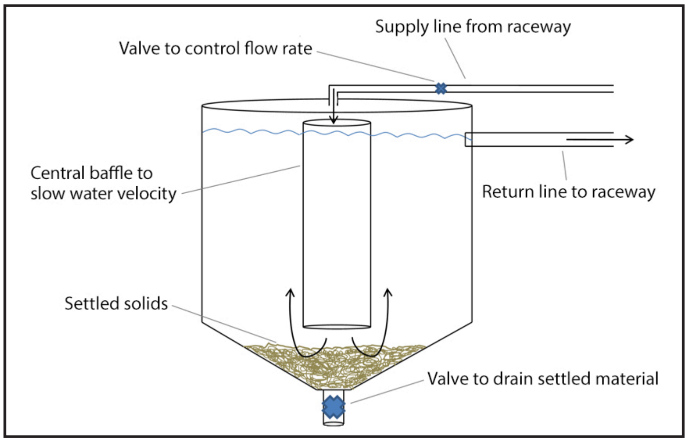

Figure 6. The design of a simple settling chamber. The settled material should be removed weekly to prevent decay and anaerobic sulfide production which has a rotten egg smell and is highly toxic to shrimp.

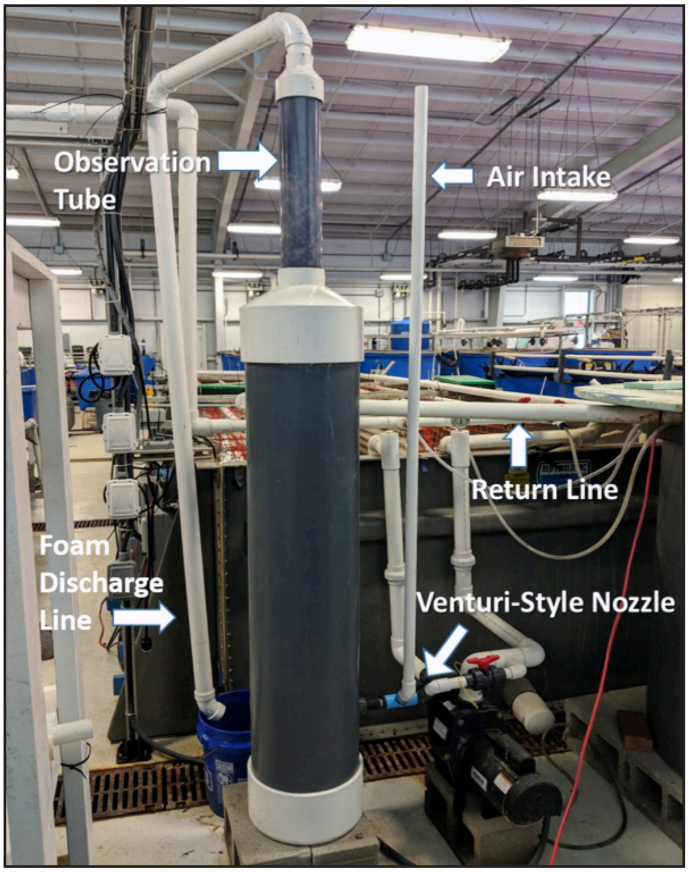

Figure 7. A pump-driven foam fractionator. There are no internal parts in this design. The Venturi-style nozzle injects air and water into the unit; a valve (not shown) on the return line dictates the height of water in the chamber.

Husbandry and management

Pacific white shrimp are commonly grown in three stages: a hatchery, nursery, and growout stage. Few indoor shrimp farms integrate all three stages of production because the number of shrimp produced in the hatchery stage (150,000+ eggs per female is common) exceeds what most farms need for the other two stages. Newly hatched shrimp are usually fed live algae, making hatchery management a somewhat specialized process. Broodstock maturation systems normally require access to clean seawater, so most hatcheries are located near the coast.

Nurseries

Once shrimp have completed the larval stages, they are fully formed shrimp known as post larvae (PLs). Most indoor shrimp farms receive PLs from a hatchery. Hatcheries commonly ship shrimp at a PL 8 to 12 size, meaning they have been PLs for 8 to 12 days. At this stage the animals are small enough that they can fit into very small volumes of water, but large enough that they are hardy and can withstand the stress of shipping. Shrimp are usually shipped in large plastic bags with water, activated carbon on the bottom, and the bags are inflated with pure oxygen gas.

Upon receipt of the PLs they can be stocked directly into growout tanks, but a nursery phase is commonly conducted. Using a nursery makes better use of space and allows the animals to be quantified. The length of time needed for the nursery phase varies, but ideally it lasts about 30 days and at that time the shrimp will be approximately 1 g average weight.

When shrimp arrive from the hatchery, they should be acclimated to the nursery tanks gradually then enumerated volumetrically. The receiving nursery tank should have water quality as similar to the conditions of the hatchery as possible. Bags from the hatchery should be floated in the nursery for about 30 minutes, then nursery water is slowly added to the bags. Shrimp should be gently placed in a known volume of water, and 5 to 10 small samples should be taken as the shrimp are mixed. Those samples should be counted, and the average number used to calculate how many shrimp were received. For instance, if there are an average of 28 shrimp per 5 ounces (148 mL) sample and the total volume is 5,000 ounces (148 L) there are approximately 28,000 shrimp total.

Growout phase

There are a several strategies regarding when to move shrimp from the nursery and how many growth phases should be used; however, moving shrimp causes mortality and it is labor-intensive. Therefore, the preferred method at Kentucky State University is to use one nursery and one growout tank; however, partial harvests from each of these tanks remains an option to facilitate production demands. When performing partial harvests, cool the water if possible, to reduce stress, be gentle with the animals, and make good estimates of how many animals are removed to adjust feed rates appropriately.

When moving shrimp to the growout tank, the number of shrimp should be estimated by weight. Ten samples of about 3.5 ounces (100 g) of shrimp should be taken from the nursery and counted. This will produce an estimate of the number of shrimp per weight, which can then be used to calculate the weight of shrimp needed to stock the desired density in the growout tank. A good starting density for a growout tank is 1 shrimp per gallon (264 per m^3). As an example, if the growout tank is 4,000 gallons (15 m^3), then 4,000 shrimp are needed. If there are 40 shrimp per ounce (1.4 per g), then 100 ounces (2,835 g) of shrimp would be needed to stock this tank.

Feeds and feeding

Shrimp are typically fed a crumbled diet at the beginning of the nursery phase. These feeds can be supplemented with live, freshly hatched *Artemia* sp. for the first week, which improves survival, especially with small PLs. Crumbled PL nursery feeds are usually high in protein (about 50 percent). As shrimp grow, the dietary protein level is typically decreased and the size of the diet particles is increased.

Shrimp prefer to eat almost continuously and they grow best on this regimen. Therefore, when the PLs are first introduced to the nursery tank, it is a good idea to make sure they have access to plenty of feed. Feed should be provided frequently, especially during the nursery stage; however, there should not be any piles of feed leftover for an extended amount of time (about 2 hours after feeding). The use of belt feeders is encouraged to provide feed frequently without exceeding the rate of consumption. If a belt feeder is used, some baking soda can be applied to the belt beneath the feed to prevent moisture absorption and caking of feed. This also allows the producer to add some alkalinity (pH buffer) to the water.

Feeding rates during the nursery phase are usually estimated using percent biomass calculations. When PLs are first added to the nursery tank, a feed rate of about 15 percent of the shrimp biomass per day should be used, and this should gradually decrease to a feeding rate of about 3 percent biomass by day 30. In the growout phase, shrimp feed rates can be calculated on a weekly basis and are based on estimated growth and feed conversion ratio.

A feed conversion ratio (FCR) of about 1.5:1 and a growth rate (GR) of 0.0529 ounces (1.5 g) per week are good starting points. Assuming there are 4,000 shrimp in the growout tank and the FCR and GR are as above, then 317 oounces (9,000 g) of feed is needed per week (FCR × GR × Number of Shrimp). Feed rates should start at about 50 percent of these full rations and increase to 100 percent over the course of about three days following stocking.

All calculated feeding rates are only estimates and assume that water quality is ideal, including an optimal temperature. Feed rates should be adjusted based on feed consumption, water quality, and shrimp health observations. However, adjustments should not be abrupt except in extreme circumstances such as very low DO concentrations. Appropriately sized nets should be used to determine whether any uneaten feed or dead shrimp are on the tank bottom. There should be no feed remaining in the tanks about 30 minutes prior to the next feeding, and there should not be more than two dead shrimp found at a time. Temperature and feed rate can be lowered to reduce animal stress if there are problems with water quality or symptoms of disease.

Health observations

Regular inspections of shrimp are needed to check the health status. Shrimp exoskeletons should be firm, the rostrum should be intact, hind guts should contain food, and shrimp should actively try to escape the net. If any of these criteria are not met, managers should consider measuring water quality and checking the adequacy of feed rates. Black spots on shrimp may be lesions caused by shrimp stabbing one another with their rostrums. This can be a problem associated with excessive density or other issues such as turning lights on and off abruptly. Black spots or black gills can also be an indication of bacterial infection. This can be due to excessive solids accumulation in the tank or excessive shrimp density. Disproportionate shrimp molting can also be an important sign of stress. If this occurs, an abundance of exoskeletons may collect on the water surface. Solids levels can be reduced or a moderate amount of sugar (table sugar) can be added to help shift the bacterial community to include more beneficial organisms and select against species such as *Vibrio* sp.

Suggested readings

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