Biofloc Technology for Super-Intensive Shrimp Culture

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Chapter 13: Biofloc Technology For Super-Intensive Shrimp Culture

Andrew J. Ray

In Brief

Super-intensive shrimp culture has been studied extensively in the last decade. We presently define super-intensive shrimp BFT systems as ones that hold above 300 shrimp/m^3 (often up to 900) and yield typically 3-6 kg/m^3, though higher yields are reported.

With these high biomass and feeding, the organic load is above the holding capacity of the system. Thus, a careful monitoring is needed and a fraction of the suspended matter has to be drained out.

Super-intensive production is still expensive, significantly above global market price of shrimp, yet may bring a profit if fresh non-frozen shrimp are sold to near-by lucrative market.

In recent years the aquaculture industry has come under scrutiny for contributing to environmental degradation. Interest in closed aquaculture systems for the production of shrimp and fish is increasing, mostly due to some key environmental and marketing advantages that such systems have over extensive systems. When water is reused, the risk of discharging pollution is reduced. This is a benefit for protecting natural resources. Furthermore, environmental regulations and discharge fees are inhibitive in most regions. Another advantage is that introduction of contaminants and pathogen from the environment to cultured animals is unlikely, especially when biosecurity measures such as source water disinfection are employed. Using closed systems limits the chance of animal escapement, helping to prevent exotic species and disease introductions to the natural environment. Because of reduced water use, high biomass, and relatively high heat containment, marine shrimp can be cultured at inland locations. This can allow producers to market fresh, never frozen marine shrimp or tropical fish to inland metropolitan locations and can help to reduce land cost and the dangers associated with coastal extreme weather events.

Several technologies can be used to overcome the constraints and demands listed above. Biofloc technology, or otherwise defined as aerated mixed ponds, are discussed in detail in this book. In discussing these systems we have typically been referring to ponds, normally rather large (in the range of 100-20,000 m^2), usually, but not exclusively lined, aerated (usually without the use of pure oxygen), and thoroughly mixed. Yields of shrimp in such systems are in the range of 10-50 ton/ha. Fish yields reach a range of 100-300 ton/ha.

To increase shrimp yields and reduce the spatial footprint, higher intensity is required, using strict suspended matter control in smaller tanks or raceways. Water quality control is still based upon the manipulation of microbial processes within the systems. Such super-intensive systems are further described in the present chapter.

A different approach, recirculating aquaculture systems, RAS, is based upon the treatment of water quality in a separate compartment using mechanical solids separation, biofilters of different types and often water sterilization, as described briefly in Chapter 3. This enables the growth of fish in a separate compartment with clear, highly controlled water. These systems allow control over water quality; however, such filtration represents substantial costs in terms of materials and energy.

One of the major advantages of culturing shrimp in biofloc systems is that multiple external filtration systems are not required, thereby potentially reducing start up and operational expenses. There is no need for external biological filtration because the microbial processes which detoxify nitrogen compounds are found within the water column; sterilization devices such as ozonation systems would only hinder these processes. Some level of control over the accumulation of biofloc particles is required, especially in the most intensive systems. However, this can typically be accomplished using a simple foam fractionator or settling system.

As mentioned in Chapters 3 and 4, a combination of nitrogen pathways occur in biofloc systems. The three major aerobic processes are described in detail in this book and by Ebeling et al. (2006): Heterotrophic assimilation, chemoautotrophic nitrification, and photoautotrophic assimilation. Each of these processes has unique benefits for shrimp biofloc systems and management goals should be carefully evaluated to determine which process, or combination of processes should be encouraged. Some examples of microbial management include increasing the carbon: nitrogen ratio (C:N) to favor heterotrophic nitrogen assimilation (Chapter 4; Hari et al., 2006), adding bacterial supplements to facilitate nitrification (Kuhn and Drahos, 2011), and encouraging photoautotrophic production by removing particles from the water to increase light penetration (Ray et al., 2009a).

An experiment was conducted at the University of Southern Mississippi's Gulf Coast Research Laboratory (GCRL) to directly compare heterotrophic-dominated and nitrification-dominated shrimp culture systems (Ray et al., 2011a). Sucrose was added to four, 500-L tanks in addition to shrimp feed to create a combined C:N of 25:1 for both sucrose and feed, while no sucrose was added to other four experimental tanks (nitrification tanks). A high spike in nitrite concentration and a continual increase in nitrate concentration were observed in the nitrification tanks, while a much lower spike of nitrite and virtually no nitrate were seen in the heterotrophic tanks. A greater concentration of solids was generated in the heterotrophic tanks. There were no significant differences between the two treatments in terms of shrimp survival and growth rate. Further experiments such as this are needed to help refine management strategies for superintensive biofloc shrimp systems.

Another major benefit of growing shrimp in biofloc systems is that, like some fishes, shrimp are equipped to take advantage of the microbial community in the water column. Numerous studies have demonstrated benefits of culturing shrimp in biofloc-rich water compared to clear water; those benefits include improved growth rate, improved feed conversion ratio, and the contribution of various nutritional qualities by the microbial community (Burford et al., 2004; Moss, 1995; Moss et al., 2006; Wasielesky et al., 2006). Shrimp production enhancement has been attributed to both bacterial (Crab et al., 2010; Hari et al., 2006) and algal (Ju et al., 2009; Kent et al., 2011) nutritional components. Fungi also occur in relatively high abundance, in shrimp biofloc systems; however, the role this heterotrophic microbial group may perform is not clear and is likely worth further investigation.

Superintensive Shrimp Culture Systems

When the biofloc microbial community is managed properly, a combination of microbial processes is capable of assimilating and cycling large quantities of nitrogen. This allows high densities of shrimp to be stocked into what have been called super-intensive biofloc systems. The term super-intensive arises from high animal stocking densities, the large inputs of nutrients that are added to support those animals, and very low rates of water exchange. Shrimp biofloc systems can be operated at varying levels of intensity; however, the focus of this chapter is specifically on super-intensive systems.

Density

Higher animal density in any aquaculture system means that the system will be more intensive, especially when little or no water is exchanged. The optimal shrimp density for a super-intensive system will depend on management and production goals. Higher shrimp density leads to a greater concentration of microbes in response to more nutrients. This will typically increase the oxygen demand of the system and augment the generation of solids. Also, higher density can slow shrimp growth rates, although a greater overall biomass may be produced.

In super-intensive biofloc shrimp culture systems it seems appropriate to refer to shrimp or shrimp biomass density in relation to volume (ex. shrimp/m^3 or kg shrimp/m^3). This is a departure from much of the literature on pond culture which refers to density or biomass per area with units such as shrimp/m^2, shrimp/acre, and shrimp/hectare. In biofloc systems the microbial community is predominantly suspended in the water column. Therefore, the level of biological filtration is dependent on water volume. Also, a major benefit of these systems is low water use, especially marine water which can be expensive at inland locations.

The Waddell Mariculture Center (WMC) in Bluffton, South Carolina, USA has been conducting super-intensive shrimp biofloc research for over a decade. In their 235 m^3 prototype raceway, researchers at the WMC stocked approximately 275 shrimp/m^3 in the year 2000, they moved to over 400 shrimp/m^3 in 2002, by 2004 they were stocking shrimp at over 600/m^3, and in 2005 they were approaching 700 shrimp/m^3 (Browdy et al., 2006). Each of these densities resulted in survival above 54% and individual growth rates above 0.9 g per week. Stocking densities above 700 shrimp/m^3 have been attempted at WMC since 2005, but with limited success.

Wasielesky et al. (2010) conducted a study to help determine maximum theoretical shrimp stocking density independent of water quality factors by growing shrimp in small containers receiving flow through water from an adjoining large tank which contained shrimp stocked at 300/m^3. Water quality in the large tank remained satisfactory and maintained that of the smaller containers. Shrimp were stocked into the smaller containers at varying densities and sizes over the course of four experiments. The authors found that as shrimp grew, the containers could support fewer shrimp, but an increasing overall biomass per container volume. Survival was 96% and shrimp grew from 0.003 g to 0.30 g in 30 days at a stocking density of 13,200/m^3. Survival was 90% or more when shrimp were cultured for 40 days and stocked at 1,760 shrimp/m^3, growing from 1.2 g to 6.7 g; likewise when shrimp were stocked at 1,180 shrimp/m^3, growing from 6.3 g to 10.6 g; and when shrimp were stocked at 880 shrimp/m^3, growing from 11.9 g to 15.7 g. This study indicates that high densities of shrimp can be cultured provided that good water quality is maintained. Although the overall system volume was larger than what was reported in the containers, the study indicates that shrimp could be grown in relatively compact culture units. Additional work may need to focus on improving growth rates at these densities.

Shrimp Production

During the period between 2000 and 2005 at WMC, shrimp production ranged from approximately 2.3-6.8 kg/m^3 (Browdy et al., 2006). The upper end of this level of production can generally be repeated at WMC during the present day. Otoshi et al. (2007) reported three superintensive shrimp production trials at the Oceanic Institute in Hawaii, USA. These trials were conducted during the years 2006 and 2007 and resulted in production of 5.7, 7.6, and 10.3 kg shrimp/m^3. Typical production levels range from approximately 3-6 kg/m^3; however, recent high production values are an encouraging indicator of the progress being made in super-intensive shrimp culture research.

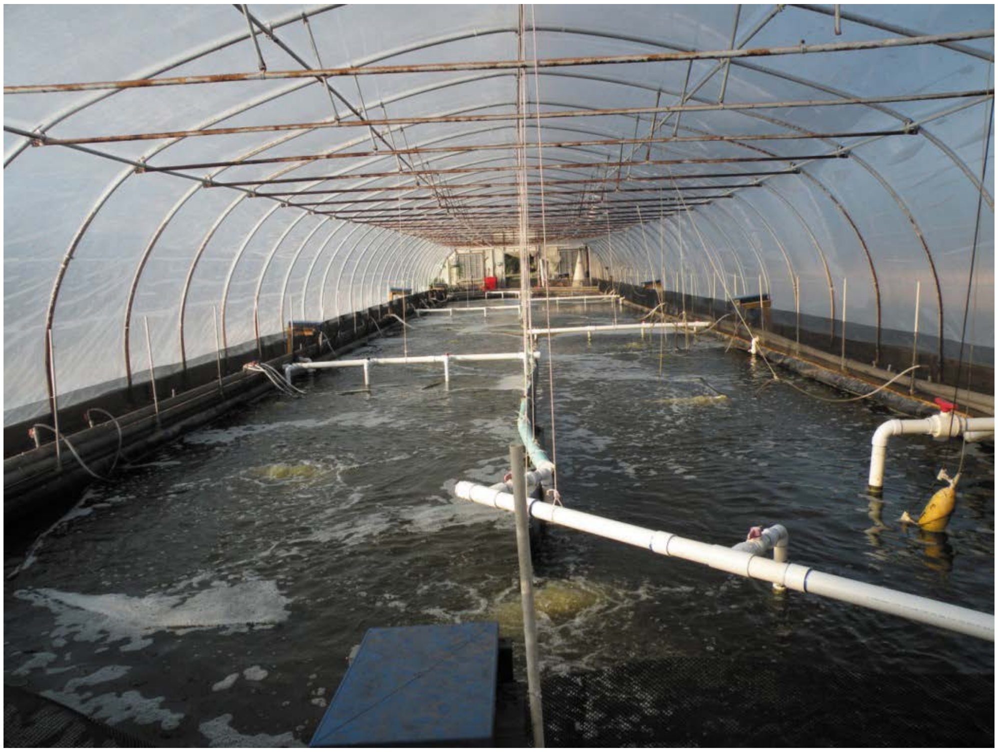
A different aspect is the water consumption needed to produce the shrimp along the cycle, this criterion includes water exchanged. According to Otoshi et al, (2007) highest production value was obtained during a trial in which over 400 liters of water were used per kilogram of shrimp produced. Using less than 130 L water/kg of shrimp, Samocha et al. (2010) reported super-intensive shrimp production ranging from 9.3-9.8 kg/m^3 in three raceways. This level of production and low rate of water use are unusual among most super-intensive shrimp culture systems.

Systems

Large, outdoor ponds are used to grow shrimp in intensive or semi-intensive biofloc-based systems. Super-intensive biofloc shrimp culture systems, on the other hand, are commonly contained in tanks or lined raceways. These systems are usually lined, preventing microbial interaction with sediments, facilitating better water movement, and aiding with solids and sludge management. Because shrimp are grown at high density, the size of these systems can be significantly smaller than ponds. This allows super-intensive systems to be operated in a closed building or in a greenhouse. An insulated building may allow for rigid temperature control, but if photoautotrophic algal processes are desired, either artificial lighting or windows are needed. Typically a less expensive structure is a greenhouse; standard frames are available as kits and a large portion of the building is usually made from inexpensive plastics. Some super-intensive systems have been constructed under greenhouse enclosures to allow photoautotrophic processes and to help capture heat from solar radiation. When heat is contained effectively, it can become economically desirable to culture tropical animals in areas that experience cool or cold conditions, thereby further enhancing location-based marketing opportunities. Also, by culturing animals indoors, biosecurity and anti-predation efforts can be facilitated more effectively.

Round tanks and small round ponds have proven effective for culturing shrimp in super-intensive biofloc systems. Circular water movement can be achieved with relatively low energy input and water homogeneity is facilitated which is an important quality in systems with high concentrations of particulates. As mentioned in chapter 12 of this book, round ponds with circular flow can have a drain at the center to remove settled solids, facilitating efficient solids management. However, it is difficult to utilize farm space effectively with round systems. Many super-intensive shrimp biofloc systems are contained in raceways: long, narrow tanks. Raceways are typically rectangular in shape, but with rounded corners. Often, a central wall or baffle spans the majority of the longer dimension (Figs. 13.1, 13.2). Water can be propelled around this wall to encourage thorough mixing of the system. Raceways are usually sloped towards one end to facilitate proper draining during harvest.

Figure 13.1: A 282 m3 raceway at The Waddell Mariculture Center (WMC) in Bluffton, South Carolina, USA



**A central wall divides the raceway and water is propelled around that wall by a combination of pumps and airlifts. A greenhouse structure covers the raceway to contain heat and facilitate radiant heating; this raceway is currently operated year-round.*

Figure 13.2: A 40 m3 raceway used for superintensive shrimp biofloc culture at the Texas AgriLife Research Mariculture Center in Corpus Christi, Texas

An explanation of Figure 13.2:

* *There is a central wall, around which water is propelled. The PVC pipes have air diffusers in them and act as air lifts, moving water vertically and forward.*

The wood frame and netting that surround the raceway are to prevent shrimp escapement.

An efficient harvest protocol is used at the Gulf Coast Research Laboratory's super-intensive shrimp culture facility in Ocean Springs, Mississippi, USA. Here, each concrete raceway has a section of the exterior wall missing at the deep end. In this section wooden boards slide into grooves in the wall and hold back the water; when the boards are removed a 50m^3 raceway can be drained in approximately 20 minutes. Water and shrimp rush into a net that rests in a harvest basin. The water is diverted to a holding pond and the net of shrimp is hoisted with an electric winch that travels along an I-beam to an ice bath, sorting table, and into a bin of ice that is hauled away by truck. Another method for harvest is to build a harvest pond below the level of the raceway. A drain in the deep end of the raceway can be opened, allowing water and shrimp to flow through a large pipe into nets tied to the pipe end in the harvest pond; these nets can then be hoisted and shrimp deposited into awaiting ice bins.

It may be less expensive to dig raceways in the ground than to build them above the ground. However, considerations should be made concerning issues such as harvest strategy and the likelihood of flooding in the area of construction, which can lead to animal escapement.

Water Movement and Oxygenation

Water movement and oxygenation are important issues in super-intensive biofloc shrimp culture systems. As with any biofloc system, water movement is necessary to keep particles in suspension. If the biofloc particles settle, pockets of anaerobic sludge often form that can release ammonia or sulfides; sulfide can be directly toxic to animals and can inhibit nitrification, thereby causing a further increase of toxic nitrogen compounds

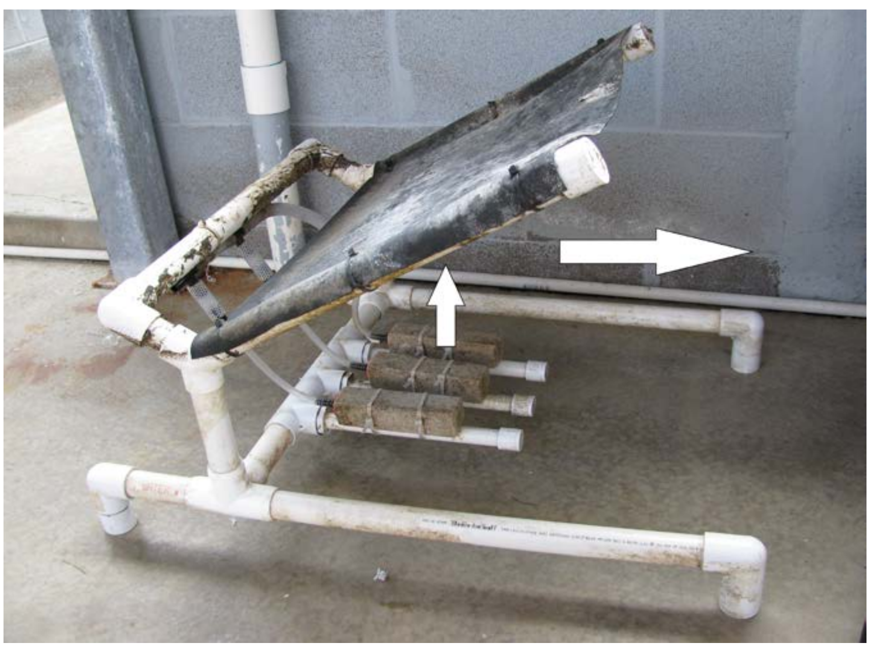
(Avnimelech and Ritvo, 2003). Maintaining adequate dissolved oxygen concentration is also of paramount importance and can be one of the most critical factors to successful super-intensive operation.

The large aerators used in ponds are typically not appropriate for super-intensive shrimp systems due to the relatively small size of these culture units. When selecting aeration devices it is important to take into account system size as well the density of animals, as some mechanisms can cause injury to densely stocked shrimp. Air blowers are commonly used in super-intensive systems. Super-intensive systems, 6.2 m^3 each, exposed to sunlight with 3.2 kg shrimp/m^3 and adequate dissolved oxygen concentrations, exclusively using blown air delivered through ceramic diffusers were described by Ray et al. (2010a). This may be an appropriate strategy for small, super-intensive systems.

In many biofloc systems water movement and oxygenation are achieved using the same equipment. Air lift mechanisms are commonly used to move and aerate water (see chapter 10). Generally, an air lift is an apparatus that uses blown air, usually passed through a diffuser. That blown air is then guided with physical structures so that it moves in a predictable direction. The density of water with air bubbles is lower than that of water without, and thus an upward movement is generated. These mechanisms typically pull water near the bottom of a culture system and discharge it above the surface, thereby helping to alleviate stratification. The low cost, low energy input, dual purpose (propulsion and aeration), and effectiveness of air lifts make them popular in super-intensive biofloc systems, although designs vary. Air lifts can move water through PVC piping, which help to move water around a shrimp raceway. Another design is seen in Fig. 13.3; rather than moving air and water through pipes, this airlift has a deflector. When air and water contact the deflector, they are propelled forward, thereby helping to circulate water around a tank.

Water pumps are commonly used to propel water and supply aeration and oxygenation in super-intensive systems. Pumps can simply be used to move water around a tank or raceway, keeping particles in suspension and homogenizing the water column. However, a more effective strategy is to attach nozzles in the water line that help to inject air and/or oxygen into the water. Venturi-style nozzles are commonly used. These nozzles are typically the same diameter as the pipe through which water is moving, except in one small area of the nozzle where the diameter is substantially constricted; in this area water velocity increases. Water pressure decreases as the flow is released to the wide outlet. The small diameter region has an opening and, due to the low pressure, gases are drawn in through this opening and injected into the water. This can be an effective means of injecting ambient air for aeration or injecting pure oxygen for oxygenation. Venturi nozzles are usually placed in a pipe line ahead of the point that water exits the line. This helps to ensure that there is ample distance (water area) for the injected gases to transfer into the water. A newly available type of nozzle known as a Tearation® nozzle (Advanced Industrial Aeration, Tampa, Florida, USA) has shown some promise in super-intensive biofloc culture systems. Samocha et al. (2010) described using Tearation® nozzles to maintain high dissolved oxygen concentrations while eliminating the use of pure oxygen injection and air blowers, which helped to reduce energy consumption.

Figure 13.3: An air lift mechanism used at the Thad Cochran Marine Aquaculture Center in Ocean Springs, Mississippi, USA



It is recommended to have back up of aeration systems by having pure oxygen on hand when operating super-intensive systems. Dissolved oxygen fluctuations can be unexpected, and unwelcome, occurrences. Nozzles are an effective way to supply pure oxygen; diffusers are also available for this purpose. Such diffusers have finer pore sizes than aeration diffusers. The use of oxygen diffusers is typically an efficient method of injecting pure oxygen; however, to adequately disperse the oxygen either a water pump or an airlift mechanism is recommended to circulate water.

Biofloc Assessment

The benefits of operating biofloc culture systems are well documented in this book and in an increasing number of scientific and technical papers. In biofloc systems, controlling the abundance of particles has proven to be an essential management step in optimizing the function of super-intensive shrimp culture systems. The terms particles, solids, suspended solids, and biofloc are all used interchangeably in this section. Ideally all particles are in suspension unless there is a specially designed chamber or area of the tank in which settling is encouraged.

In less intensive biofloc systems particle management may not be an important issue, although monitoring of concentration is advised. In more intensive culture systems particles can rapidly become concentrated due to greater feed inputs. Carbohydrate addition also contributes to greater particle concentration and bacterial biomass; if carbohydrates are used as a management strategy, a plan to manage particles should also be considered.

There are three commonly used methods of inferring the concentration or abundance of particles: total suspended solids (TSS), turbidity, and settleable solids (or floc volume, FV). TSS is the most accurate method of determining solids concentration. A known volume of water is passed through a previously cleaned and weighed 0.7 µm filter, the filter is then rinsed to remove salts, dried, allowed to cool, and weighed to determine the weight of filtered material. The results of TSS are usually reported as mg TSS/L. There can be some variability between samples; the use of at least two replicate filters is recommended to help decrease variance. The filters used for TSS can be expensive, a drying oven and filtering apparatus are also required, potentially making TSS somewhat cost inhibitive for some farming operations. TSS also takes a considerable amount of time to generate data.

APHA (2005) defines turbidity as “an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample.” This procedure produces a number, reported as Nephelometric Turbidity Units (NTU), in a short period of time and can be a reliable indicator of solids concentration. However, the color of a water sample can affect the results of this procedure. Water that is brown in color can produce a higher turbidity value than water that is green in color, independent of the TSS concentration. The price of a turbidimeter is usually well worth being able to make this measurement. It is recommended that turbidity be compared to TSS on at least an occasional basis, if possible, to make sure that turbidity is adequately following changes in TSS.

Another method of characterizing solids in biofloc systems is the use of an Imhoff Cone to measure floc volume. The floc volume is determined by placing a water sample in an Imhoff Cone and allowing particles to settle (See Chapter 11). This method, is simple, does not demand expensive equipment, and is easily adapted to farm conditions and thus can be a useful tool; however, some suspended particles often do not settle, therefore the measurement may not be directly correlated to TSS or turbidity.

In research settings, all three methods of inferring particle concentration are often used to help understand particle dynamics. Further characterization of particles can include chemical measurements such as particulate organic carbon concentration, physical measurements such as particle size which can be attained microscopically, or biological characterization such as algal pigment measurements.

Biofloc Concentration Management

External settling chambers are one mechanism used to control suspended solids concentration in super-intensive shrimp culture systems. Ray et al. (2010a) found that settling chambers (Fig. 13.4) placed adjacent to super-intensive shrimp culture systems reduced TSS by 59%. The authors also found that nitrate and phosphate were reduced by about 60% and alkalinity was increased by 33% compared to systems without settling chambers. These could have been indications that denitrification was occurring in the settling chambers. Furthermore, Ray et al. (2010a) found that shrimp biomass production was increased by 41% through the use of settling chambers. This study helped to demonstrate the benefits of solids management in these systems and showed that management may be achieved using simple, cost-effective settling chambers.

Figure 13.4: A settling chamber adjacent to a larger shrimp culture tank. Water is moved to the settling chamber using an air lift mechanism

**A ceramic air diffuser located in the PVC pipe submerged in the shrimp culture tank moves water up the pipe and into the settling chamber. Water then enters a larger diameter pipe, causing velocity to slow. Particles settle on the bottom and clarified water at the surface of the settling chamber returns back to the shrimp culture tank.*

External settling chambers are convenient because particles settle outside the culture unit and shrimp are not directly exposed to settled material. However, such chambers can, at times, return ammonia to the culture system, likely due to the decomposition of organic matter. Settling particles from the water column is a low-energy, efficient way to control biofloc concentration. Settling is usually most effective at removing large particles above approximately 100 µm in diameter. Settling chambers with cone bottoms are preferred, as the cone shape helps with the removal of settled material.

Another device that is used by some super-intensive system managers to regulate particle concentration is a foam fractionator. Foam fractionators require that a nozzle and a pump that creates adequate pressure to operate the nozzle be used. There are commercially available fractionators, but they can be readily constructed on site for a substantially lower cost. A primary advantage that these units may have over settling systems is that fractionators can remove a wide range of particle sizes, including some dissolved solids. Some disadvantages are that fractionators can be inconsistent in what and how much they remove and they can use a larger amount of water than settling systems. Samocha et al. (2010) compared the use of external settling chambers to the use of foam fractionators in super-intensive shrimp raceway systems. They found that nitrate was lower in the systems with settling chambers, likely due to denitrification, but that there were no significant differences in shrimp production between raceways with either type of solids management device. Further research may be needed to help determine what solids filtration is best for super-intensive shrimp systems. It is possible that foam fractionators would better facilitate long term water reuse, as they may remove dissolved contaminants that can otherwise accumulate over time.

Several other types of solids management filters are available, such as bead filters. However, for super-intensive shrimp culture systems in which a goal is to use the lowest volume of water possible, settling systems and fractionators are currently the most popular devices.

A critical issue facing biofloc and other RAS systems is the disposal, or preferably the reuse, of removed material. Chapter 8 of this book addresses using this material as a source of nutrition for aquatic animals, thereby recycling otherwise wasted nutrients. Other options include using the material as a fertilizer for plants. Use of material from saltwater shrimp operations can be problematic due to the low tolerance of many plants to salt. However, one option that is being explored is using the waste as a fertilizer for halophytes, such as those used in salt marsh or dune restoration projects (Ray et al., 2011b).

The Effects of TSS Concentration

Control over the concentration of TSS is important for super-intensive biofloc systems. It is unclear exactly how particle concentration management leads to improved shrimp production, although some possibilities include reduced gill clogging, promotion of a younger and potentially healthier microbial community, possible removal of nuisance organisms, or reduced biochemical oxygen demand which may lead to increased oxygen availability for culture animals.

Ray et al. (2009b) found that by reducing particulate concentration in superintensive shrimp systems, photosynthetically active radiation was significantly increased in the water column, as was primary productivity. Ray et al. (2010b) reported that the removal of particles reduced the overall abundance of bacteria, cyanobacteria, nematodes, and rotifers. These studies help to demonstrate that simple particle management can cause substantial changes in the microbial communities of super-intensive systems. More research is needed to understand whether such changes may affect animal production.

In a recent super-intensive biofloc study Brunson et al. (2011) operated five experimental treatments; in one treatment solids were not removed, and in the remaining four treatments settling chambers were operated for increasingly longer lengths of time. In the most extreme treatment settling chambers were operated continuously and had a 250 µm mesh bag on the return line. These authors found a significant inverse correlation between shrimp biomass production and TSS. They found that with decreasing TSS concentration came a decrease in chlorophyll concentration and a decreased feed conversion ratio (FCR), although there was no significant effect on shrimp growth rate or final individual weight. Almeida et al. (2011) conducted a similar study and also found improved FCR with lower TSS. Almeida et al. (2011) also observed generally improved survival at lower TSS concentrations, yet weight gain and FCR were about the same for shrimp grown at TSS of 100, 200 or 400 mg/l. Shrimp performance was significantly lower when TSS was 800 mg/l.

Studies have indicated that, in general, a lowering TSS concentration above a set value can improve shrimp production. However, Ray et al. (In Press) found that maintaining TSS concentrations below approximately 200 mg/L may have reduced the nitrification process in commercial scale, 50 m^3 shrimp raceways, whereas in raceways with a TSS concentration of approximately 300 mg/L nitrification proceeded.

More research is needed to determine the optimal TSS concentration range for super-intensive systems. Production goals, waste remediation techniques, and nutrient cycling strategies should be considered in determining the level at which TSS is managed.

Economic Considerations

Currently there are not many commercial super-intensive biofloc systems. Although the technology is slowly being adopted by some companies, for the most part these systems are operated by research institutions. The dominant reason for this is that cost of production needs to be lowered substantially to enhance profitability. Also, special marketing efforts should be made to help augment the sale price of animals that are cultured in these systems.

An overview of economic factors influencing the profitability of super-intensive biofloc systems was provided by Hanson et al. (2009). These authors created a model with which economically important production variables could be analyzed in detail. Total baseline cost of production in the southeastern United States was estimated to be 5.40 USD per kilogram. The authors found that the biological improvement that could lower production costs the most was survival. A 20% increase in survival was capable of decreasing production costs by 0.80 USD per kg.

Another important objective that should be met to make these systems profitable is an improvement in the consistency of production. Currently, final production values are often variable among the research institutions that study these systems in the US, due to both biological and mechanical problems. Some of the problematic biological issues include poor growth rate, an inability to maintain adequate pH, likely due to high rates of microbial respiration and high CO_2 concentration, and bacterial infections in animals. Some of the mechanical issues include pump failures and oxygen supply system failures. Research is ongoing to solve biological problems; mechanical problems will likely be solved with redundancy in important life support systems.

The location of super-intensive biofloc systems has important economic implications. In cooler climates temperature must be augmented to facilitate adequate growth rates of tropical animals. In some areas a greenhouse enclosure may be suitable; however, in other areas an insulated building may be more appropriate. Typically, it is more efficient to directly heat the water in which animals are cultured, although in some cases heating the air space in a building can be effective and can reduce condensation, thereby helping to protect metal structures from corrosion. Location can also affect the cost of water. If rearing marine animals, the cost of seawater or artificial salts can be substantial at inland locations. For this reason, research on super-intensive biofloc systems is typically centered around strict water use limitations.

Typically the most expensive variable cost for super-intensive systems, and many aquaculture systems, is feed. Hanson et al. (2009) estimated that feed costs represent 37% of the variable costs of operating super-intensive biofloc systems. Much work is being conducted to help remedy this problem. Feeds that would not be nutritionally complete for other aquaculture systems are being explored, with the idea that the dense microbial community in super-intensive systems can help to supplement some important feed components. For instance, low protein feeds and feeds with protein sources other than traditional marine fish products have been used with encouraging success (Azim et al., 2008; Ray et al., 2010a).

The fact that super-intensive biofloc systems can incorporate environmentally responsible aquaculture practices and the animals can be fed specialty diets, some of which are almost entirely plant-based, can lead to marketing opportunities. Marketing products as environmentally friendly or nutritionally exceptional can enhance the potential profitability of these systems.

Conclusion

Biofloc shrimp culture systems are a viable alternative to traditional shrimp aquaculture. When the microbial communities in these systems are managed appropriately, according to the goals of the shrimp producer, they can be operated as super-intensive systems. Although this brings greater risk of mechanical or biological complications, such as dissolved oxygen depletion, substantially larger shrimp crops can be produced using very little land or water.

Super-intensive shrimp culture systems require a somewhat unique set of engineering and management criteria. Many of these issues are still being explored by the scientific community as well as by members of the aquaculture industry. Important concerns include water propulsion, oxygenation, appropriate shrimp density, solids management, and waste reuse to name a few. The future surely holds a place for super-intensive biofloc systems or some adaptation of this technology if responsible aquaculture development is to progress.

Practical Implications and Tips

1. *Very dense biomass of L. Vannamei (300-800 shrimp/m^3 can be controlled. We do not know yet if these values hold for other shrimp species*.
2. *Super-intensive systems have clear advantages when production is near to metropolitan areas and/or in cases where temperature control in the cold season is essential. It is not yet competitive with other commercial shrimp production methods*.
3. *The very dense biomass and high feeding rates require strict control of suspended matter.*

Further Research Needs

The development of super-intensive capacity and its viability are very dramatic. Yet, further work is needed to develop this approach to be economically competitive with other production approaches.

Improving feed utilization, energy conservation and reducing infra-structure cost seem to be of high priority

Recommended Reading and Cited Literature

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