Global Aquaculture Advocate

ANIMAL HEALTH & WELFARE (/ADVOCATE/CATEGORY/ANIMAL-HEALTH-WELFARE)

The Shrimp Book: Intensive production of shrimp

Sunday, 1 July 2012

By Dr. Yoram Avnimelech

Intensive systems can support 100 times higher production than extensive systems

Intensive shrimp production systems can support high output in a small area. Photo by Dr. Nyan Taw.

The common desire to achieve higher and higher yields – justified by reasons that include environmental regulations limiting water disposal, biosecurity concerns and water scarcity and/or cost – has led aquaculture toward more intensive production systems. The general evolution of pond intensification is outlined in Table 1.

Avnimelech, Pond intensity levels, Table 1

Pond Type	Intervention	Approximate Shrimp Yields * (kg/ha/cycle)	Limiting Factors
Extensive ponds based on natural or minimal feed	Minimal feeding with grains, farm and home residues	Over 100-500 (Over 2,000) *	Limits of primary production, food chain efficiency

Extensive fed ponds	Feeding by complete diet pellets	500-2,500 (2,000-4,000) *	Early morning oxygen
Semi-intensive ponds with nighttime and supplemental aeration	Nighttime or emergency aerators, ~1-5 hp/ha	1,500-8,000 (4,000-10,000) *	Sludge accumulation, anaerobic pond bottom
Intensive, fully aerated ponds	24-hour aeration under 20 hp/ha (pure oxygen, if needed), completely mixed	8,000-20,000 (20,000-100,000) *	Water quality control

Table 1. Pond intensity levels, approximate yields and limiting factors. Adapted from Avnimelech et al., 2008.

Shrimp can be grown at very high density in aerated ponds. Yet with the increased biomass, water quality can become a limiting factor due to the accumulation of toxic metabolites, the most notorious of which are ammonia and nitrite. Natural control mechanisms, based mostly on algae uptake of ammonium, are not capable of controlling nitrogen in intensive systems.

Water quality control

Three different approaches can be used to control water quality:
• Replacing pond water with external water, usually at high exchange rates in super-intensive ponds, raceways or tanks.
• Recycling the water through an external biofilter to treat and purify it.
• Treating water quality within the pond system using algae (partitioned aquaculture ponds) or bacterial communities (bioflocs).

Since high water-exchange rates are generally not acceptable due to environmental, biosecurity and water scarcity considerations, other means to control water quality are needed. One common approach in shrimp hatcheries and nurseries, as well as quite a few fish production systems, is to recirculate the water through biofilters to improve water quality. Systems that use this technology are called recirculating aquaculture systems (RAS).

Recirculating aquaculture systems

RAS systems are based on the recirculation of water between the production unit and the water treatment module. Water is pumped out of the production component (usually tanks or rather small lined ponds), undergoes a series of treatments to improve various physical and chemical parameters, and then returns to the production unit. These systems are well proven and can be obtained commercially with production capacities as high as 100 kg/m^2. However, the operation of RAS units is quite costly, both in investment and running costs. RAS water treatment components are large, rather complex and energy-dependent.

Biofloc technology

Water treatment with feed recycling in intensive ponds can be achieved through the development of biofloc technology, which is based upon the manipulation of micro-organisms in zero- or low-water-exchange, mixed and aerated ponds. The intrinsic features of any intensive pond are high aeration rates and thorough mixing. An additional characteristic that encourages microbial dominance in intensive ponds is the accumulation of organic substrates. Biofloc technology takes advantage of active microbial communities to control water quality and recycle feed.

When water exchange is limited, organic matter builds up in culture water. Organic matter is the substrate needed for the development of a heterotrophic microbial community – microbes that get their energy by metabolizing organic molecules. Intensification, aeration, mixing and limited water exchange all lead to the development of microbial dominance in ponds. Typical features of microbial-dominant systems as compared to algae-dominant systems are given in Table 2.

Avnimelech, Comparison of algae-and bacteria, Table 2

Factor	Algae Control	Bacteria Control
Energy source	Solar radiation.	Mostly organic matter.
Occurrence	Ponds with low organic matter concentration. Algae density increases with the availability of nutrients up to limitation of light.	Dominance in ponds with high supply and concentration of organic substrate, normally limited to intensive ponds with zero or low water exchange, though common at nutrient-rich sites.
Sensitivity toward environmental variables	Light is essential (activity lower on cloudy days). Crashes are common.	Does not need light, adapts to a variety of conditions. Crashes are exceptional.
Effect on oxygen	Oxygen is produced during the day, consumed at night.	Oxygen is consumed.
Relevant activities	Primary production produces organic matter and oxygen. Ammonium uptake.	Degradation of organic matter. Nitrification, production of microbial protein.
Inorganic nitrogen control	Uptake driven by primary production. Maximal capacity 0.7 g ammonium/m2/day.	Uptake of nitrogen affected by the carbon:nitrogen ratio of organic matter. Practically unlimited capacity.
Potential capacity	Normally, daily primary production does not exceed 4 g carbon/m^2	Limited by substrate concentration and rate constant of degradation.

Table 2. Comparison of algae-and bacteria-controlled systems.

The size of the microbial population depends on the supply of organic matter, and the stability of the aerobic community depends on an ample supply of oxygen. The driving force for the proliferation of microbes is the addition of organic matter, the major source of which is feed.

The number of bacteria in zero-exchange intensive ponds can approach 109 cells/mL. The bacteria form flocs up to a few millimeters in size that are a mixture of bacteria, organic residues and microorganisms such as protozoa and zooplankton.

Proper manipulation of the microbial biomass enables effective water quality control, mostly through conversion of the potentially toxic inorganic nitrogen species to microbial protein. In turn, the microbial protein can be utilized to feed the shrimp.

Microbial flocs, shrimp nutrition

In a study of the uptake and utilization of 15 microbial flocs by shrimp, the proportion of daily nitrogen uptake of the shrimp contributed by the natural biota was calculated at 18 to 29 percent. Protein utilization in biofloc ponds is almost double that found in conventional ponds due to a recycling of the excreted nitrogen into utilizable microbial protein. The protein is "eaten twice." First the protein in the feed is taken up, and eventually, unutilized residues are eaten again by harvesting of the bioflocs.

Protein is a costly component of aquafeeds, and in addition, there are environmental concerns regarding fishmeal-based protein. Thus, the increased utilization of protein and resulting lower protein percentage in feed have major economic and environmental implications.

Unutilized feed and feed components are discarded in conventional RAS ponds soon after feed applications. Feed residues have a long hydraulic retention in biofloc systems. Food web recycling enables better utilization of feed. The feed requirement in shrimp tanks with bioflocs is reduced to about 70 percent of that needed in open systems.

Limitations of biofloc systems

Biofloc systems have some limitations. Excessive turbidity can have negative effects on fish and antagonize algae development that, in some cases, leads to better shrimp growth. The draining of excessive sludge is a means to control turbidity.

Biofloc-based ponds require greater oxygenation than clearwater ponds, but about 50 percent of the additional oxygen needed for the microbial metabolism is offset by the omission of the oxygen requirement for nitrification. In addition, pumping is hardly needed in these ponds. The energy needed for pumping in biofiltered ponds is about the same as that needed for aeration.

Commercial development

Belize Aquaculture was the first large-scale farm practicing and developing biofloc technology. Much of the know-how for running commercial biofloc shrimp ponds was derived from the experiences gained at Belize Aquaculture. Various companies in Indonesia are producing shrimp on a very large scale using biofloc systems, as reported by Dr. Nyan Taw in various scientific forums. The scale of these operations is immense, covering thousands of hectares of ponds.

In addition, much research on biofloc systems has been carried out at institutions like Waddell Mariculture Center in South Carolina, USA, and elsewhere, often using greenhouses due to temperature limitations. The use of greenhouse-enclosed raceway systems and the high yields obtained may justify growing shrimp all year – even in regions where climatic conditions limit growing shrimp in open ponds to one season a year.

Perspectives

With relatively low use of land and water, intensive systems can presently support about 100 times higher production than extensive systems.

Intensive recirculating aquaculture systems demand high investment and maintenance costs. RAS are successfully used to produce high-value fish or in shrimp hatcheries and nurseries. Scaling up RAS systems to open shrimp production ponds does not seem practical.

Biofloc technology can use variable degrees of intensity. The investment and running costs needed for bioflocs systems are lower than those needed for RAS. The cost of constructing biofloc ponds can be lower than that to construct earthen ponds scaled to produce equivalent yields.

Important constraints are the essential needs for reliable power, input sources and marketing infrastructure, and proper back-up systems. Without such support, the development of small-scale farms efficiently applying biofloc systems will be constrained.

(Editor's Note: This article was originally published in the July/August 2012 print edition of the Global Aquaculture Advocate.*)*

Author

DR. YORAM AVNIMELECH
Professor Emeritus
Department of Environmental and Civil Engineering
Technion, Israel Institute of Technology
Haifa, 32000 Israel
agyoram@tx.technion.ac.il (mailto:agyoram@tx.technion.ac.il)