STANDARD OPERATING PROCEDURE MANUAL FOR THE SHALLOW WATER SUPER-INTENSIVE STACKED RACEWAY SYSTEM FOR SHRIMP PRODUCTION AT THE TEXAS AGRILIFE MARICULTURE RESEARCH LABORATORY, PORT ARANSAS, TEXAS

BY

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INTRODUCTION

The shallow water super-intensive stacked raceway system (patent pending) addresses many environmental and production constraints that have hindered shrimp (*Litopenaeus vannamei*) aquaculture from sustained success in the United States. The tanks are stacked atop one another so that vertical production can be achieved which reduces water and land use, along with the size of the building. The stacked raceway system also increases management efficiency. By constructing the raceways in buildings, optimum production water quality, temperature, and salinity can be achieved along with maximum bio-security. The indoor stacked system will utilize a designed system of transfers and partial harvests so that optimum harvest biomass can be achieved with every crop.

A pilot system of the raceways has been constructed at the Texas AgriLife Research Laboratory in Port Aransas, TX. This system has shown promising results for survival and growth and has the potential to achieve 1,200,000 kg/ha water footprint in shrimp production each year, which is far more than the current U.S. pond shrimp production rate. Standard operating procedures were developed to guide operation and maintenance of the stacked raceway system. Included is information on system design, daily maintenance, feeding, water quality management, transfers and harvesting. Procedures were developed through several production trials from May 2011 to June 2012.

I. BACKGROUND

The concept of shrimp farming began as early as the 1930's in Japan with the first successful spawning of *P. japonicus* by Dr. Fujinaga. This breakthrough led the way for many growout methods to come about later (Whetstone et. al 2002).

In 1963, Harry Cook was successful at spawning two shrimp species native to the Gulf of Mexico in *P.setiferus* and *P. aztecus* (Kungvankij 1984). After these initial trials with local species, U.S. researchers began to try non-native species in the 1970's such as *M. japonicus, P. monodon, L. vannamei*, and *L. stylirostris*. *L. stylirostris, in* particular showed promise for North American farming in the 1970's and 1980's. Research trials for grow out took place from South Carolina to Texas, as well as in Hawaii, and in countries to the south such as Nicaragua, Belize, Mexico, Peru, Colombia, Venezuela, and Brazil. *L. vannamei* were first spawned successfully in Florida in 1973 (FAO 2012). Hatcheries were successful first, then later grow out became successful as further knowledge was gained (FAO 2005). Shrimp farming success was seen on a grand scale in the 1970's and 1980's in Ecuador which garnered interest in the industry in many other areas of the world (Lightner 1995). In the U.S., commercial shrimp farming operations began in Texas in 1981 (McFarlane 1999). Shrimp farming expanded rapidly in the 1980s due to large supplies of wild larvae, lack of disease issues, decreasing wild catch numbers, and increasing market prices (Moss 2002). Texas became the leader in shrimp farming in the United States in the 1990's due to its ideal location climatically and its agricultural friendliness. Texas shrimp farmers enjoyed lucrative profits using semi-intensive pond culture models for production (McFarlane 1999). However, in the mid-1990's, Texas saw the introduction of Taura

Syndrome Virus (TSV) and White Spot Syndrome Virus (WSSV) which had devastating effects on the industry (Lightner 1995).

Shrimp are cultured across the world, with 78.3% grown in Asia (FAO 2012). The domination of shrimp culture by Asian countries is primarily due to the arrival of WSSV and other diseases in Latin America in the 1990's, which caused a decline in production (Lightner 1995). Recently, shrimp farming in Latin America has begun to rebound due to the use of specific pathogen free (SPF) and specific pathogen resistant (SPR) strains of shrimp. Extensive and semi-intensive shrimp farming is commonly practiced in Latin America, whereas Asian farmers generally use intensive production methodologies (FAO 2006). Farming of shrimp is most commonly undertaken in earthen ponds constructed near the coast to facilitate filling with water from a nearby bay or estuary. This water also serves as a source of natural productivity, used to reduce feed costs. In more intensive pond systems, shrimp are stocked at densities in excess of 40 shrimp/m^2 necessitating higher water exchange rates (Hopkins et al. 1995) as well as supplemental aeration (Boyd et al. 2001). A typical semi-intensive pond grow out operation in the U.S. is capable of producing 2,722 to 4536 kg/ha/year according to Dr. Addison Lawrence (personal communication), while more extensively managed ponds in Asia produce 20-500 kg/ha/year (Chowdhury et al. 2010).

Shrimp production in the Eastern Hemisphere is led by Thailand, Indonesia, India, China, and Vietnam, while production in the Western Hemisphere is led by Mexico, Belize, Ecuador, and Brazil (FAO 2010). Production of farm-raised marine shrimp is increasing at a mean annual rate of 12%, with production totaling 2 million metric tons in 2005 and 2.3 million metric tons in 2006 (Hedlund 2007). The predominant farmed species of shrimp is Pacific white shrimp (*L. vannamei*), which lends itself to domestication and is easier to grow than other shrimp species

(Hedlund 2007). Penaeid shrimp account for 73.3% of all crustaceans grown, which is 3.7 billion metric tons per year. Although this is 5% of all aquaculture yearly production, it is 23% of yearly aquaculture revenue and is increasing at a rate of 15% yearly (Mathiesen 2010). Worldwide farming of *L. vannamei* has grown from 475,363 tons in 2002 to 2,720,929 tons in 2010. In the same time period, total market value has increased from $2.295 billion (U.S.) to $11.284 billion (U.S.). These numbers make shrimp the most important fishery commodity in terms of value (Aquaculture 2010). This consistent demand and growing market value have generated enormous interest in the shrimp farming industry. To satiate the growing demand for shrimp, many new farming technologies are continuously evaluated to provide increased production.

The four types of commonly used strategies to grow shrimp are referred to by the following industry-adopted terms: extensive, semi-intensive, intensive, and super-intensive. Extensive systems usually rely on tides for water exchange and larval stocking. Shrimp nutrition is primarily provided by natural foods that propagate in these systems and ponds are usually harvested at 150 to 500 kg/ha/crop with 1-2 crops occurring each year. Semi-intensive culture systems consist of ponds stocked with hatchery-reared larvae. Water exchange is accomplished by pumping to provide oxygen and for the removal of waste materials. Supplemental feeds are used in addition to existing natural feed. Harvest yields approximate 500-4,000 kg/ha/crop at a rate of two crops per year. Intensive systems are constructed at sites where production units can be completely dried and prepared between crops (Whetstone et al 2002). Ponds are generally smaller to give farmers more control over culture conditions. Supplemental feed is heavily relied upon and aeration is semi-continuous to continuous. Production levels vary widely, dependent upon technology applied to the grow-out methodology and of 8-20,000 kg/ha/crop. Production systems with the highest biomass density are referred to as super-intensive. This can involve the use of indoor raceway systems having minimal water exchange but high levels of aeration. These systems are bio-secure and have as small an environmental footprint as possible. Production of 28-68,000 kg/ha/crop can be realized in these systems (FAO 2012).

The major constraints to shrimp farming in open pond systems include several environmental factors. These bottlenecks consist of seasonal and daily meteorological changes, natural disasters, contamination of estuarine ecosystems, and the fact that open systems allow diseases to be easily transmitted (Boyd 2003; Paez-Osuna 2000). Seasonal changes in atmospheric conditions make the temperate zones of the world unable to compete with the tropics due to restricted grow-out periods (typically only one crop per year vs. two and a half (Boyd et al. 2001). Additionally, outdoor locations experience daily flux in environmental conditions (e.g., temperature). Natural disasters such as hurricanes and tsunamis can devastate shrimp ponds by washing out dams and mixing stocks between ponds (Paez-Osuna 2000). Finally, one of the biggest constraints to earthen pond shrimp farming is close proximity to marine/brackish waters. These areas represent a multiple use conflict situation in terms of sport fishing, resorts, and ecology of estuarine habitats. Estuarine ecosystems are vital for marine life (Pompe and Rinehart 1995; Hopkins et al. 1995). If the land is in high demand, it is usually not cost-effective to build a farm there due to cost and amount of land required. On the other hand, if coastal land contains important estuarine ecosystems, it may not be an appropriate site for construction of a large farm due to environmental regulations (e.g., permitting) as well as negative feedback from environmental and various user groups (Hopkins et al. 1995). The last major disadvantage of pond systems is the fact that they are open to the environment which allows for easier spread of disease from external sources. Disease epizootics have been a major issue for pond farmers in various parts of the world, most notably susceptibility to catastrophic diseases such as White Spot Syndrome Virus (WSSV) and Yellow Head Virus (YHV) in Asia and Taura Syndrome Virus (TSV) in Latin America (Flegel and Alday-Sanz 1998; Lightner et al. 1998).

Although shrimp farming has achieved success in many tropical areas of the world, there have not been any consistently successful shrimp farming ventures in the U.S. capable of competing with foreign-grown shrimp. The main reasons for limited success in the U.S. are the aforementioned seasonal environmental constraints, intense and often prohibitive regulatory policy, high cost/low availability of coastal land and high operational costs (e.g., energy and labor). Although there has been a lack of success, it has not prevented U.S. researchers and entrepreneurs from trying new technologies that would enable profitable and sustainable shrimp farming. The U.S. is third in seafood consumption in the world, consuming $4.8 billion in 2009—of this, shrimp were most highly consumed, with a per capita consumption rate of 4.1 lbs/year (NOAA 2010). Despite this, the U.S. remains a very small producer, accounting for less than 1% of shrimp produced globally (FAO 2009). Although the current low level of production might be seen as unfavorable with respect to building an industry, there is a growing demand that provides excellent incentive for competition. If domestic production costs can be reduced to a level in line with that of foreign sources, then a sizable profit might be foreseen from decreased import and shipping costs alone.

Perception of researchers varies on a specific direction for development of the shrimp farming industry in the U.S. Ultimately, production efforts must be competitive with imported shrimp from tropical areas. Despite various viewpoints, some common principles include: 1) shrimp must be grown indoors in tanks in closed systems; 2) biomass stocking densities must be high (>10 kg/m^3); and 3) production facilities must be environmentally sustainable (Boyd 2003;

Boyd et al. 2001; Paez-Osuna 2000). In other words, production needs to be predictable and disease limited. In temperate zones (e.g., south Texas), farmers have traditionally produced only one crop per year in earthen ponds (Boyd et al. 2001). This production cannot compete with tropical areas (e.g., Central America, Southeast Asia) that have warmer climates year-round supporting production of at least two and a half crops each year (Boyd et al. 2001). In addition to having advantages with respect to variability of climatic factors, indoor systems are inherently more bio-secure than ponds (Ogle 1998). Shrimp must be grown in tanks, raceways, or some other small types of enclosures that allow the farmer to closely monitor the production process so that maximum growth and survival can be achieved (Moss 2002). They must also be grown at high biomass stocking densities (>10 kg/m^3) so that input costs can be covered and profit margins can be large enough to keep farms operational (Samocha et Al 2002). The last defined principle is that shrimp farms must be environmentally sustainable, which means they must not destroy fragile ecosystems through excessive construction or discharge of nutrient loaded water (Hopkins et al. 1995). As with any energy-expensive industry, the super-intensive production of shrimp requires sufficient life-cycle assessment to identify long-term constraints to production.

Using general principles researchers agree need to occur for shrimp production to become widely successful in the U.S., the stacked raceway concept was borne. The system employed vertical stacking of tanks to utilize less space and was fully indoors for bio-security and temperature management. Shrimp transfers were planned during growout so that optimal densities could be reached in tanks as often as possible, which also decreased production area. The planning phase for the Shallow Water Super-Intensive Stacked Raceway System for Shrimp Production began in 2009 and construction was begun in December, 2010. Construction was completed in March of 2011 and experiments were initiated at that time. The first year of experiments were undertaken in order to streamline the system for optimal shrimp growth and survival. The system's current design was completed in May of 2012. Shrimp were stocked into the top level of the stacked raceway system at approximately 1 g in size. They were grown for four weeks, and then transferred into the next lower level after being re-stocked at an optimum density. This process was repeated every four weeks for the 16-week growout process as the shrimp were transferred from level 1 to level 4 in the stacked system. System production was estimated to exceed 1,200,000 kg/hectare of water used per year, which would clearly exceed that of traditional pond production systems by two orders of magnitude.

STANDARD OPERATING PROCEDURE

DESIGN

1. Raceway Tanks

Black fiberglass raceways (n = 16) used in the pilot system at the Texas AgriLife Research Mariculture Laboratory (Port Aransas, TX) are shown in Appendix 1 and were built by Red Ewald, Inc. (Karnes City, TX). Raceways were 0.8 m (w) x 5 m (l) x .35 m (h) for a total surface area of 4 m^2 (volume = 1.4 MT). An “inverted v” design for the bottom of the raceway was used along its longitudinal length in order to encourage circular flow along the sides. The “inverted v” portion of the raceway terminated 20 cm in front of one end of the raceway in order to maintain circulation of water. At the lower end of the raceway, the “inverted v” also terminated 20 cm before its end with a 15 cm deep sump situated below the bottom of the tank for collection of residual feed, molts and fecal material. This sump contained a 2” drain line in which the internal standpipe is positioned to keep water height at 12 cm above the crest of the “inverted v” in the center of the tank. In addition to the internal standpipe in the sump, the sump contained a 4” harvest valve with an opening directed outward from the tank for use during transfers and harvests of shrimp. The top raceway was constructed with additional ribbing to provide extra weight support encountered at the top level. Raceway design is depicted in Figure 1.

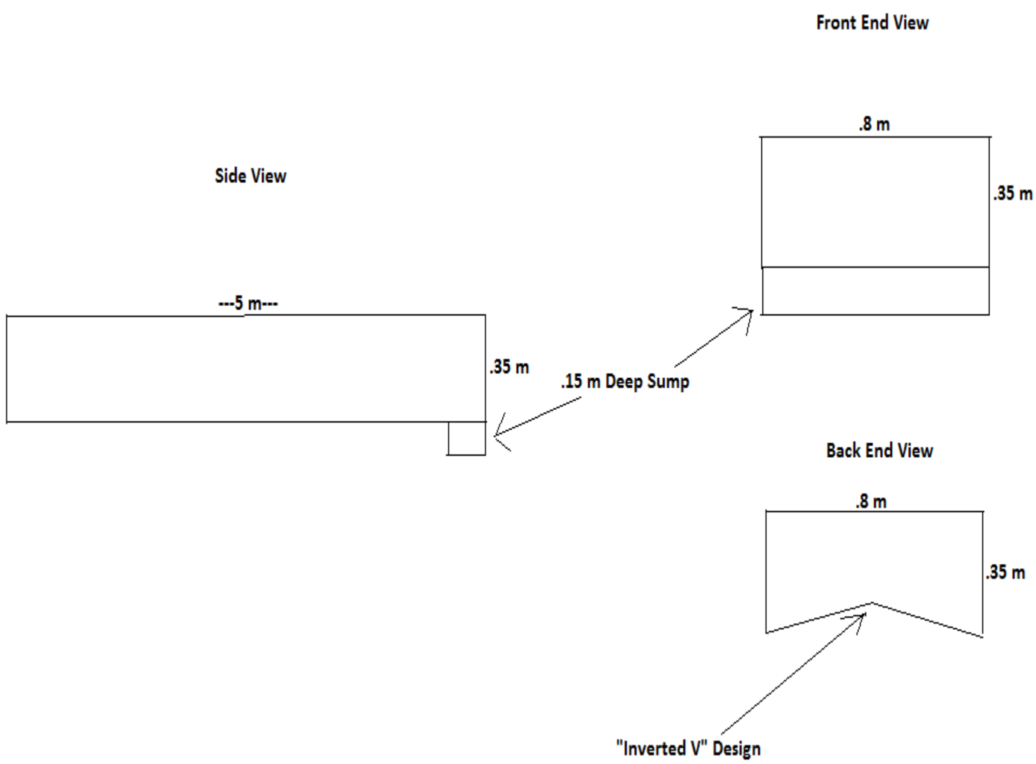


Figure 1. Raceway Tank Design

2. Framing

Raceways were organized into four stacks of four raceways each. Structural support was provided by cedar beams as cedar is known to harden in salt air. This cedar was determined to be non-toxic to shrimp. Boards used underneath the outside lip of the raceways were 2" x 8". These outside boards were attached to eight 4" x 4" cedar wood posts (4 on each side of the raceway) for support from the ground. The 4" x 4" posts were affixed into 8" pyramidal concrete blocks to provide a firm base on the ground. Raceways were constructed one level at a time due to room configuration, causing the 4" x 4" posts to be attached atop one another using 5/8" lag bolts as dowels. Additional boards (2” x 4”) were also used to connect 4” x 4” posts and provide additional weight support underneath the raceways. All boards were bolted together using 3/8’ stainless steel bolts, so that the cedar framing would be held firmly together.

3. Aeration

Aeration was achieved using 3/4” diffuser tubing provided by Colorite Plastics (Austin, TX). The design is depicted in Figure 2. The aeration was associated with a central bar extending the length of the raceway which also served as a baffle creating a cross-sectional upwelling affect allowing water flow in opposite directions on each side of the tank, resulting in circular flow. This aeration bar was held at the top of the crest by twine tied off to either side of the raceway. The aeration bar was attached to 1/2” PVC pipe filled with 3/8” re-bar to maintain the bar on the bottom of the tank and to ensure that maximum amounts of air would come in contact with the water. Two aeration bars half the length of the sump (directional flow air bars) were also used to promote water flow down the entire length of the tank in each direction, further assisting circular flow around the tank. Aeration was provided by a 10 hp vortex blower and distributed to each tank via a 3/4” valve at each end of each raceway. From this valve, 3/4" tubing was divided by a 3/4" wye fitting between the directional flow air bar and the air bar down the center of the tank. Before the tubing reached the air bar down the center of the tank, it was divided by a second 3/4" wye fitting between the directional flow air bar which causes water to round the end of the tank and the air bar down to the center of the tank. The same air input sequence was used to provide air for each end of the raceway.

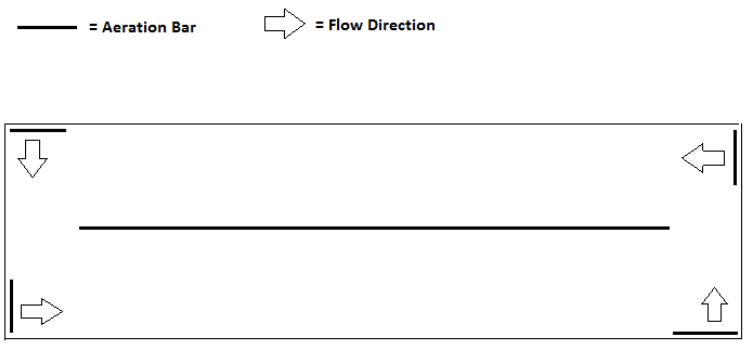


Figure 2. Aeration Design

4. Re-circulating System

The raceway re-circulating system used for solids and nitrogen removal was located in rooms adjacent to the system. There were a total of four re-circulating systems with one attached to each of the four raceway stacks. The systems consisted of seventy 0.5 m^3 tanks situated above rapid sand and UV filters. Tanks were filled with bio-balls to fulfill the role of bio-filtration. Water from raceways was passed downward through trickling bio-filters into three settling tanks. It was then subjected to rapid sand and UV filtration by an electric pump, and cycled back into the raceways.

5. Lighting

Lighting was determined to have no positive effect on shrimp growth so it was kept to a minimum in the system. The small amount of light used served as a buffer against scaring shrimp into jumping when overhead room lighting was turned on.

6. Netting

Netting over tanks consisted of 1/8" Ace Knotless Netting manufactured by (Memphis Net & Twine, Memphis, TN). This netting was 4 ft deep and stretched down the length of the raceway tightly over the top to eliminate openings. Netting was attached to the sides of the tank by plastic grommets pulled tightly over stainless steel screws affixed to cedar wood sideboards surrounding the raceway. One grommet was used between each of the 4" x 4" cedar wood posts down the side of the raceway.

7. Feeders

Feed distribution was via 24-hour belt feeders (Zeigler Brothers Feeds, Gardners, PA) attached to the front end and above each raceway. They were affixed to a 2" x 4" cedar wood frame attached to the end of the raceway using 3/8" stainless steel bolts. Removal of the feeders was required for harvesting. Feed entered the raceway via PVC pipes directly in front of the air bar and water input for ease of distribution via water current. To avoid sticking of feed, feeders and PVC pipes were sprayed with food-grade silicon spray.

STOCKING

1. Optimal Densities

Previous experimental trials in the raceways (detailed later) have shown that the optimal stocking density for shrimp in the raceway system is determined by an optimal harvest density. The optimal harvest density is 3 kg/m^2, so shrimp are stocked to reach this density at the end of their 4 week growing period.

2. Handling/Acclimation

Shrimp were handled as little as possible during the stocking process in order to avoid imparting stress: they were kept wet at all times and never held out of water for longer than 30 seconds. During stocking, water temperature was checked to ensure close proximity to that of stocking tanks. Acclimation of shrimp to water temperature in receiving tanks was at a rate no more than 2 degrees Fahrenheit per hour.

COUNTING

Although counting is not necessary after the nursery phase in traditional shrimp farming methods, it is vital to the success of the stacked raceway technology to ensure optimal harvest densities will be achieved at the end of every 4-week growing period. Two types of counting strategies were used in the stacked raceway system: gravimetric and via automated counter.

1. Gravimetric

Gravimetric counting is the traditional way in which shrimp are counted and requires minimal technology. This was accomplished by collecting a sample set of shrimp out of the general population, weighing the sample set, then dividing it by the number of shrimp weighed to determine a mean weight. The general population was then weighed, usually in a mesh bag or fish basket, and divided by the previously attained mean weight to determine the number of shrimp in the general population. A 5% percentage for water weight was factored in for juvenile shrimp as they retain more water on their bodies than adult shrimp. Gravimetric counting was possible for operation of the pilot scale system of the stacked raceways, but would not likely be possible for a commercial sized raceway system due to the high volumes of shrimp being weighed.

2. Larcos

The Larcos Counter^{TM} (Larcos, LLC, St.Petersburg, FL,) was designed to count shrimp in the water column as opposed to the dry environment of the gravimetric system. Counting was achieved via line-scan camera adjacent to a light source in an imaging chamber that relayed images to specifically designed software that counted the shrimp in real-time as they were being transferred or harvested from a tank. The counter was applied to the stacked raceway system in several trials and was successful in obtaining counts consistently averaging above 95% accuracy when compared to gravimetric counting of the same tank. The counter was attached to the harvest valve of the raceway, and PVC elbows and piping were used to direct the shrimp into a lower raceway after passing through the counter. Once the desired number of shrimp for the optimal stocking density had been transferred into the raceway, the harvest valve was closed and shrimp in the source tank were harvested.

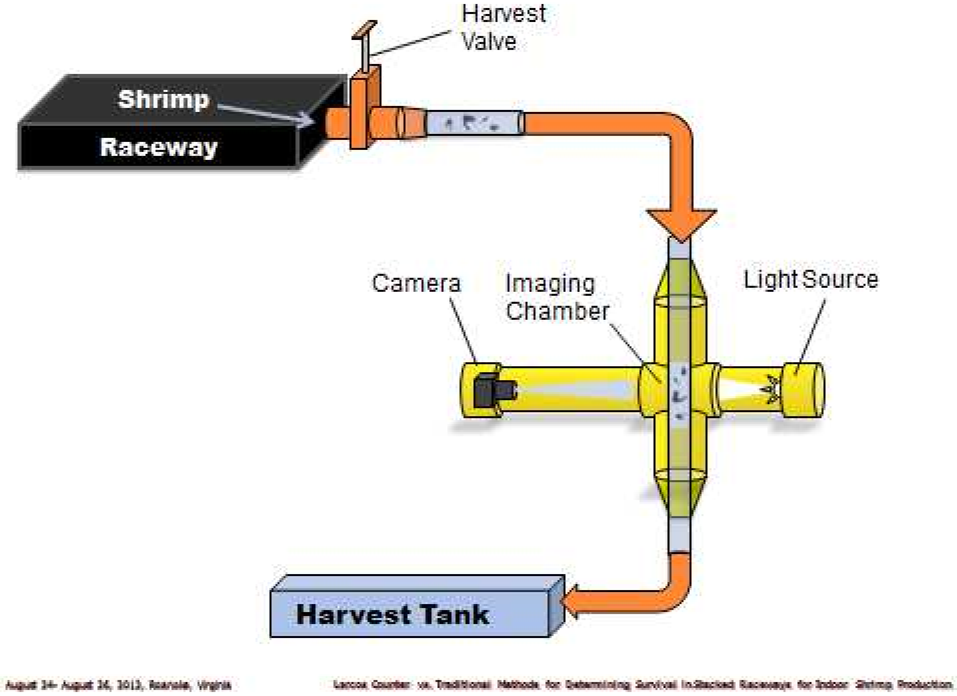


Figure 3. Diagram of the Larcos Counter

TRANSFERS/HARVESTING

Shrimp were stocked into the upper raceways of each system at a wet weight of 0.4 - 0.8g and subsequently grown for a period of four weeks. The targeted harvest weight was 2.5 - 3.5g and these shrimp were then transferred to the next lower raceway. Shrimp were drained through the Larcos™ Counter until a target stocking biomass density of 3 kg/m^2 after four weeks was reached. After an additional four weeks, shrimp were again harvested and transferred to the next lower level. At this point, it was estimated that shrimp would be approximately 9-10 g in weight. As with previous transfers/stockings, a biomass density of 3 kg/m^2 was again targeted. The aforementioned process was repeated for another four weeks, until shrimp achieve a mean weight of 17-18g. The process was repeated for a fourth set of four weeks during which shrimp would achieve a final mean weight of 25-26 g before harvest.

FEEDING

1. Feed Types

Shrimp in the stacked raceway system were fed a dry, pelleted feed designed for maximum nutrition value. Feeds tested were sinking and floating pellets having either 32% or 35% protein. A satisfactory commercial diet was not identified, but best results were shown with a 35%-protein Standard Reference Diet (SRD) manufactured in-house. Technology was not available to produce this feed in floating form.

2. Feeding in the Juvenile Stage

The juvenile stage of shrimp was loosely defined as the period between just less than 1 g to 4 g in size. Shrimp in the top tier of the stacked raceways were stocked at this stage. A feeding schedule based on shrimp wet weight is shown in the following table:

RWY 12-02 Brinson Lingenfelter 6-10-12
Feed curve for 2 feeds

Edit cells highlighted in yellow. Calculation of correction for different stocking weights is hidden in columns T through Y.

Growth trial	Stocking date	Culture tank	Stocking weight (g)	FCR	Days	Number Stocked		Survival/ day (%)		Stocking day correction		Feed	SRD 35%	Wenger 32%	
												Moisture	10%	10%	
RWY 12-02	06/13/12		1.0000	1.50	28	1500		100		27		Dry matter	90%	90%	

Edit cell highlighted in blue. Other cells will adjust.

day	date	weight (g)	weight gain (g)	FCR	Number of shrimp removed	Number of shrimp remaining	Feed: SRD 35% feed based on FCR %	Feed: SRD 35% feed based on FCR (g/tank)	feed adjustment %	feed adjustment (g/tank)	total feed (g/tank)	feed crumble size	Feed: Wenger 32% based on FCR %	based on FCR (g/tank)	feed adjustment %	feed adjustment (g/tank)	total feed (g/tank)	feed crumble size
0	06/13/12	0.9605	0.1100	1.50		1500	100%	275.00	0%	0.00	275.00	18/14	100%	275.00	0%	0.00	275.00	0.8 mm
1	06/14/12	1.0701	0.1200	1.50		1500	100%	300.00	0%	0.00	300.00	18/14	100%	300.00	0%	0.00	300.00	0.8 mm
2	06/15/12	1.1880	0.1300	1.50		1500	100%	325.00	0%	0.00	325.00	18/14	100%	325.00	0%	0.00	325.00	0.8 mm
3	06/16/12	1.3143	0.1400	1.50		1500	100%	350.00	0%	0.00	350.00	18/14	100%	350.00	0%	0.00	350.00	0.8 mm
4	06/17/12	1.4495	0.1500	1.50		1500	100%	375.00	0%	0.00	375.00	18/14	100%	375.00	0%	0.00	375.00	0.8 mm
5	06/18/12	1.5937	0.1600	1.50		1500	100%	400.00	0%	0.00	400.00	14/12	100%	400.00	0%	0.00	400.00	1.5 mm
6	06/19/12	1.7474	0.1700	1.50		1500	100%	425.00	0%	0.00	425.00	14/12	100%	425.00	0%	0.00	425.00	1.5 mm
7	06/20/12	1.9107	0.1800	1.50		1500	100%	450.00	0%	0.00	450.00	14/12	100%	450.00	0%	0.00	450.00	1.5 mm
8	06/21/12	2.0841	0.1900	1.50		1500	100%	475.00	0%	0.00	475.00	14/12	100%	475.00	0%	0.00	475.00	1.5 mm
9	06/22/12	2.2677	0.2000	1.50		1500	100%	500.00	0%	0.00	500.00	12/7	100%	500.00	0%	0.00	500.00	2.00 mm
10	06/23/12	2.4620	0.2100	1.50		1500	100%	525.00	0%	0.00	525.00	12/7	100%	525.00	0%	0.00	525.00	2.00 mm
11	06/24/12	2.6671	0.2200	1.50		1500	100%	550.00	0%	0.00	550.00	12/7	100%	550.00	0%	0.00	550.00	2.00 mm
12	06/25/12	2.8835	0.2300	1.50		1500	100%	575.00	0%	0.00	575.00	12/7	100%	575.00	0%	0.00	575.00	2.00 mm
13	06/26/12	3.1113	0.2400	1.50		1500	100%	600.00	0%	0.00	600.00	12/7	100%	600.00	0%	0.00	600.00	2.00 mm
14	06/27/12	3.3510	0.2500	1.50		1500	100%	625.00	0%	0.00	625.00	12/7	100%	625.00	0%	0.00	625.00	2.00 mm
15	06/28/12	3.6027	0.2700	1.50		1500	100%	675.00	0%	0.00	675.00	12/7	100%	675.00	0%	0.00	675.00	2.00 mm
16	06/29/12	3.8669	0.2900	1.50		1500	100%	725.00	0%	0.00	725.00	12/7	100%	725.00	0%	0.00	725.00	2.00 mm
17	06/30/12	4.1437	0.3100	1.50		1500	100%	775.00	0%	0.00	775.00	12/7	100%	775.00	0%	0.00	775.00	2.00 mm
18	07/01/12	4.4336	0.3300	1.50		1500	100%	825.00	0%	0.00	825.00	12/7	100%	825.00	0%	0.00	825.00	2.00 mm
19	07/02/12	4.7367	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
20	07/03/12	5.0535	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
21	07/04/12	5.3841	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
22	07/05/12	5.7290	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
23	07/06/12	6.0883	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
24	07/07/12	6.4625	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
25	07/08/12	6.8517	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
26	07/09/12	7.2564	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
27	07/10/12	7.6767	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
28	07/11/12	8.1131				1500												

Figure 4. Feeding Schedule

During this time, shrimp were fed feed size 18/14 from just less than 1 g to 1.5 g in size. At 1.5 g shrimp are changed to feed size 14/12, and at 2 g they are fed 12/7 size feed. All feed pellet size changes are done by this format: Day 1: 75% previous feed,25% new feed, Day 2: 50% previous feed, 50% new feed, Day 3: 25% previous feed, 75% new feed to adjust the shrimp to eating larger size pellets. These changes were initiated when the feed curve called for them. Juvenile shrimp were fed according to weekly weight gain using an expected FCR of 1.5. In order to facilitate feed management, rations were adjusted daily to reflect mortality.

3. Feeding in the Linear Growth Phase

The linear growth phase of shrimp is herein defined as the stage between 4 g in size to maturation in which shrimp grow at a constant rate. For this reason, the same feed rate can be used weekly assuming 100% survival. For the first day of production, shrimp were fed at a rate conducive to generating 1.5 g/week weight gain. They were then fed at a 2.0 g/week growth feeding rate on the second day to allow for lower feeding rates due to transfer stress. Days 3-28 were fed at a 2.5 g/week growth and to achieve a feed conversion rate (FCR) of 1.5. Daily recommended feed amounts should be determined from this information and amount fed should reflect these amounts. In order to determine the exact required feed amount, feed amounts were adjusted daily in increments of 20 g based upon consumption the day before. Tanks were visually inspected twice daily to estimate consumption rates. If >99% of feed was consumed (not floating or accumulated in tank) after 24 hours, the feed was be increased 20 g. If 90-99% of feed was consumed (not floating or accumulated in tank) after 24 hours, the feed amount remained the same. If >10% of feed is not consumed (floating or accumulated in tank) after 24 hours, the feed amount was decreased. If significant mortality (>5 shrimp) was noticed when siphoning, feed was administered every other day until mortality ceases. Recommended feed amounts were changed to reflect mortality.

4. Feed Amount Calculation

As previously mentioned, daily feed amount in the linear phase was calculated by multiplying a set FCR (1.5) by the weekly expected gain (2.5 g). The resultant amount was divided by seven to determine the amount of daily feed needed per shrimp.

WATER QUALITY

Total ammonia nitrogen was checked in all tanks each morning using Tetra EasyStrips 6-in-1 and Ammonia test strips. Although not as accurate as bench-top titration methods, they provided a quick measurement allowing the operator of the stacked raceways to react quickly to any potential water quality issues. Dissolved oxygen, water temperature, and salinity were determined using a hand-held YSI meter.

1. Water Exchange Rate

Water exchange in the raceway system was kept at as low a level as possible without deteriorating water quality and causing stress to the shrimp. The most successful re-circulating exchange rate so far in the stacked raceways was 1 gpm, or 929% of water exchange daily in the system. In addition to the re-circulating exchange, new water was added to the system at a rate of 0.5 gpm to keep water quality from deteriorating. These exchange rates were intended as a baseline for exchange, but anytime water quality was anticipated to vary from safe levels of any factor, it was exchanged at a much higher volume. This was accomplished by removing flow restrictors from the re-circulating water input into the tank as well as the new water input into the re-circulating system. High volume water exchange continued until water quality improved, typically about four hours.

2. Dissolved Oxygen

Dissolved oxygen levels were maintained above 4.5 mg/L at all times. Levels were adjusted by increasing air flow into the raceway.

3. Water Temperature

Water temperature was maintained between 31 and 32.5° C at all times for maximum shrimp growth. Temperature control was accomplished by an existing on-site pneumatic heater connected to the re-circulating system. This system is very sensitive and was operated on a basis of a half-turn tighten=0.5°C and vice versa. The black plastic knob on the pneumatic mechanism above the re-circulating system room door was used for adjustments.

4. Salinity

The typical range of salinity at which shrimp growth is maximized is from 8 - 40 ppt. Water for the stacked raceway system in Port Aransas was obtained from the Corpus Christi Ship Channel which had a salinity between 33 and 40 ppt during experimental trials. Although shrimp tolerate wide variations in salinity, rapid changes are viewed as potentially harmful. For this reason, acclimation processes for salinity were similar to that of water temperature.

5. Ammonia (NH_3^-)

Ammonia levels were maintained below 3.0 ppm in the raceways, which was the assumed level toxic to shrimp (Addison Lawrence, personal communication). Ammonia levels can be decreased by removing excess feed and feces from the tank, lowering the feed rate, and high volume water exchanges.

6. Nitrite (NO_2^-)

Nitrite levels were maintained below 3.0 ppm in the raceways, which was the assumed level toxic to shrimp (Addison Lawrence, personal communication). Ammonia levels can be decreased by removing excess feed and feces from the tank, lowering the feed rate, and high volume water exchanges.

7. Nitrate (NO_3^-)

Nitrate levels should be kept below 200 ppm in the raceways, which was the assumed level toxic to shrimp (Addison Lawrence, personal communication). Ammonia levels can be decreased by removing excess feed and feces from the tank, lowering the feed rate, and high volume water exchanges.

8. Alkalinity (A_T)

Alkalinity levels were maintained in excess of 120 mg/L in the raceways, in order to buffer seawater against rapid swings in pH. Alkalinity was maintained by high volume water exchanges or the addition of $NaHCO_3$.

9. pH

pH was maintained between 7.5 and 8.0 in the raceways at all times, a pH that has been shown to be favorable for good shrimp survival and growth. pH was maintained by high volume water exchanges or the addition of $NaHCO_3$.

PRODUCTION POTENTIAL

The stacked raceway system possesses the unique potential to produce 13 crops each year due to its indoor location and four-week production period cycles. Each raceway intermittently receives shrimp from the above tank so that shrimp are continually produced. Raceways can be stacked either four or seven tiers high, depending on budget and production goals.

1. Four-Tier Stack

In the four-tier raceway stack, shrimp can be stocked into the top raceway after a four-week nursery phase. After four weeks in the top raceway, they would be stocked into the next raceway at a density equivalent to 3 kg/m^2 at the end of the four-week grow-out period. Non-transferred shrimp would be partially harvested and sold at a lower than target size. This process would be repeated twice more with the fourth transfer being the final harvest. Due to the raceways being stacked vertically, the four-tier stack system would capable of producing 4.64 kg/m^2 of shrimp per harvest which is equates to 60.32 kg/m^2/year of water footprint. This is equal to 603,200 kg/year per hectare of water footprint.

2. Seven-Tier Stack

In the seven-tier raceway stack, shrimp will be stocked into the top raceway after a four-week nursery phase just like the four-tier stack. After four weeks in the top raceway, the shrimp will be stocked into the second and third highest raceways in anticipation of reaching 3 kg/m^2 at the end of the next four week production period. By splitting into two raceways instead of one at this stage, less small size shrimp have to be prematurely harvested, which allows for greater potential profit without increasing seed or footprint cost. At the end of the second four week production period, the shrimp and transferred into the fourth and fifth highest tanks, and partial harvesting is again used so that the next phase will reach the optimal harvest density. At the end of the third four week production period, the shrimp are transferred into the sixth and seventh highest tanks for four more weeks of grow out before the final harvest for that crop. Using the seven-tier system instead of the four-tier system causes production to double, so 9.28 kg/m^2 of shrimp is produced each harvest, equaling 120.64 ka/m^2/year of water footprint. This is equal to 1,206,400 kg/year per hectare of water footprint.

MAINTENANCE DUTIES

1. Daily Checklist

AM – Raceway Room

___Lights in room dimmed

___Oxygen on in all tanks

___Water flow into all tanks

___Feeders moving

___Funnels not clogged

___Netting pulled down around tanks

AM – Bio-filtration Room

___No erratic pump noise

___Incoming sea water flowing into all systems

___Re-circulating water flowing into all sumps

___Re-circulating water flowing into all bio-balls

___Make sure all sumps have feed accumulated

PM – Raceway Room

___Lights in room dimmed

___Oxygen on in all tanks

___Water flow into all tanks

___Feeders moving

___Funnels not clogged

___Netting pulled down around tanks

PM – Bio-filtration Room

___No erratic pump noise

___Incoming sea water flowing into all systems

___Re-circulating water flowing into all sumps

___Re-circulating water flowing into all bio-balls

___Make sure all sumps have feed accumulated

2. Daily Duties

___AM Checklist (8:00 AM)

___Sand filters in bio-filtration rooms will be backflushed each morning (8:00 AM)

___Bio-filtration settling sumps will be siphoned each morning (8:20 AM)

___Incoming sea water should be checked for flow each morning (8:00 AM)

___Raceway settling sumps will be siphoned each morning (8:40AM)

___Raceways will be examined along their entire length for mortality, feed accumulation, bio-fouling, or any other potential hindrances to optimal growth each morning (8:50 AM)

___Each water inlet will be checked for flow (9:10 AM)

___Dissolved oxygen, Temperature, pH, and Salinity will be recorded for each raceway (9:30 AM), and heaters should be adjusted accordingly

___Water quality will be checked in each tank with test strips and values should be recorded (9:45 AM), and water should be exchanged accordingly

___Remaining feed pellets should be assessed so feed amounts can be prepared (1:00 PM)

___Feed will be added to the automatic feeders once daily (1:30 PM)

___PM Checklist (4:45 PM)

3. Monthly Checklist

Raceway Room

___Clean all internal standpipes

___Clean feeder belts and funnels

___Spray feeders belts and funnels with silicon

Bio-filtration Room

___Clean all spray nozzles above bio-balls

4. Six Month Maintenance

___Service Water Pumps

___Service Roots Blower

___Service UV Filters

___Clean and Service Rapid Sand Filtration

RESEARCH TRIALS

1. Rwy 11-01

Brinson A. Lingenfelter

5-16-2012

The objective of Rwy 11-01 was to define the standard operating procedures for four-week grow out periods in the shallow water super-intensive stacked raceway system. The experiment was conducted in eight tanks in Level 3 and 4 raceways. Water depth was set at 10, 12, 14 and 16 cm above the crest. Clear, re-circulating water was used and tanks were stocked at 300 shrimp/tank at an average size of 10 g. Emphasis was put on optimizing survival over growth.

Daily Activities

- Sand filters in bio-filtration rooms will be back-flushed each day
- Dissolved oxygen, Temperature, pH, and Salinity will be recorded in each raceway stack once per week
- 12 Hour feeders will be filled at 8 AM and 5 PM

Water Exchange

- Re-circulating exchange rate will be 4 gpm
- New water will be added at 1 gpm

Water Temperature

- Water Temperature will be kept as close to 32°C as possible

Feeding

- Level 3 raceways will receive Zeigler 32% Protein floating feed and level 4 raceways will receive Zeigler 32% Protein sinking feed

Water Quality

- Dissolved Oxygen, Salinity, and Temperature will be checked with the YSI meter and recorded onto the provided data sheet
- Stacks should be analyzed for TAN, NO_2, NO_3, pH and Alkalinity once weekly

Results

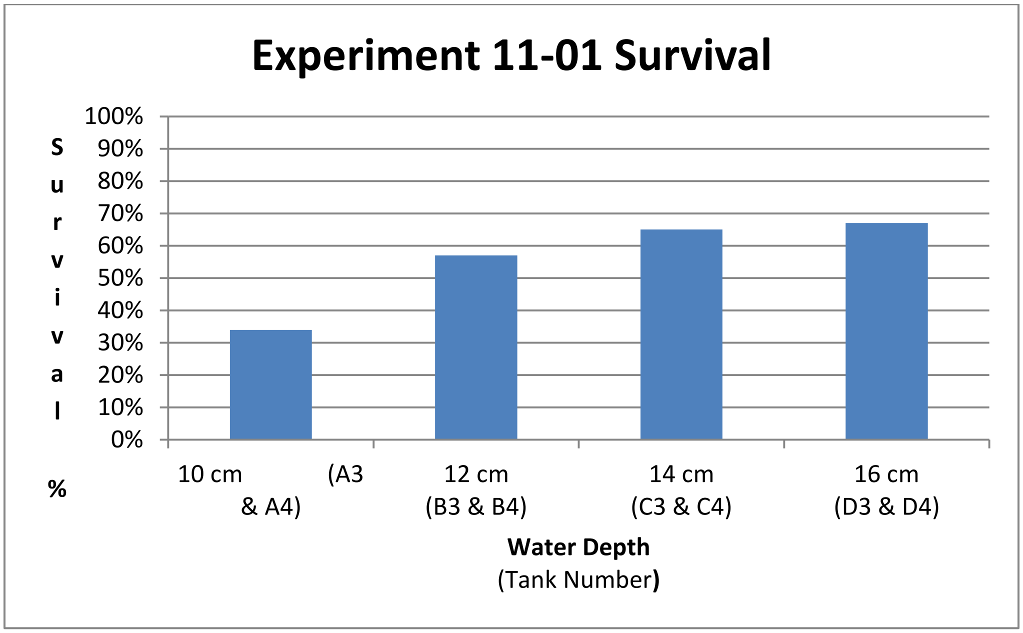


Figure 5. 11-01 Survival

Survival averaged 56% for this experiment but was consistently higher in the tanks with higher depths of water. There was a noticeable drop-off below the depth of 12 cm above the crest. It was deduced from this experiment that 12 cm would be the best depth to use going forward. Mass mortality was noticed during this experiment and was attributed to build up of feces and uneaten feed in the sumps in the raceways and bio-filtration system. It was decided that these sumps would be more closely monitored experiments in the future.

2. Rwy 11-02

Brinson A. Lingenfelter

6-20-2012

The objective of Rwy 11-02 was to define the standard operating procedures for 4-week grow out periods in the shallow water super-intensive stacked raceway system. The experiment was run in 4 tanks on level 1. Water Depth was 12 cm above the crest. Clear Water RAS was used and tanks were stocked at 2000 shrimp/tank at an average size of 0.7 g. Emphasis was put on optimizing survival over growth.

Daily Activities

- Sand filters in bio-filtration rooms will be back-flushed each day
- Dissolved oxygen, Temperature, pH, and Salinity be recorded in each raceway stack once per week
- 12 Hour feeders will be filled at 8 AM and 5 PM
- Raceway sumps will be siphoned daily
- Sumps in bio-filtration system will be siphoned daily

Water Exchange

- Re-circulating exchange rate will be 4 gpm
- New water will be added at 1 gpm

Water Temperature

- Water Temperature will be kept as close to 32°C as possible

Feeding

- Raceways will receive Rangen feeds size 1, 2, and 3 as they increase in size.

Water Quality

- Dissolved Oxygen, Salinity, and Temperature will be checked with the YSI meter and recorded onto the provided data sheet
- Stacks should be analyzed for TAN, NO2, NO3, pH and Alkalinity once weekly

Results

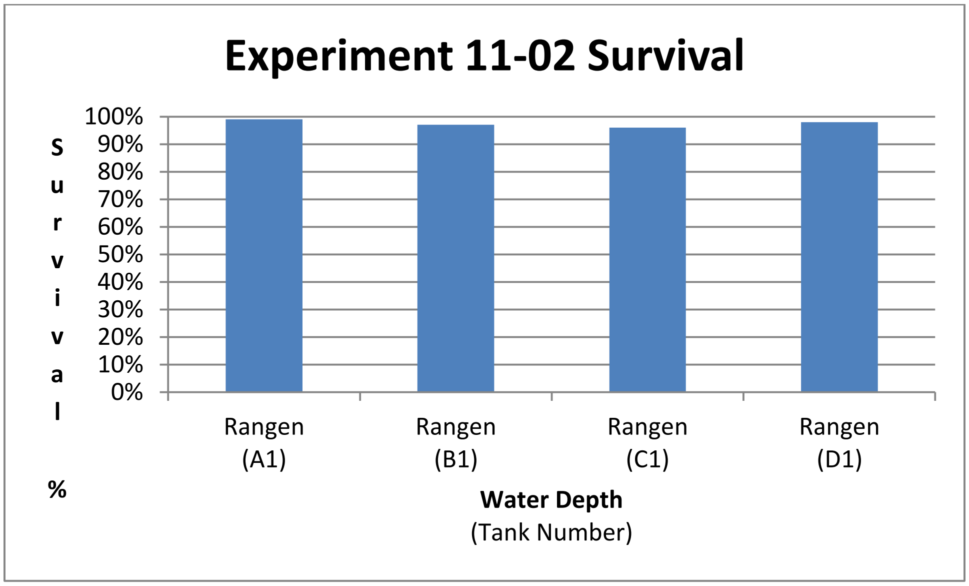


Figure 6. 11-02 Survival

Experiment 11-02 showed remarkably high survival results for shrimp in the top raceways with the lowest rate being 97%. This showed two things; that the Rangen starter feeds fed progressively in size 1, 2, and 3 as shrimp grew were nutritionally beneficial for juvenile shrimp, and that the tanks with netting stretched tightly over the top were keeping shrimp from jumping out of the tanks better than the lower tanks that had netting down the sides.

3. Experiments 11-03 through 11-06

Experiments 11-03 through 11-06 were conducted in the stacked raceways in the late summer and fall of 2011 and showed no significant results. These experiments were plagued by mass mortality events, shrimp jumping from the tank, and poor initial construction design. It was decided in the late fall to shut down the raceway system in order to re-work several initial construction designs including the air delivery system, the in-tank aeration, the water inputs, feeder location, and, chiefly the netting. After all of these changes were made, the raceways were started again in 2012 for further experimentation.

4. Rwy 12-01

Brinson A. Lingenfelter

5-31-2012

The objective of Rwy 12-01 was to define the standard operating procedures for four-week growout periods in the shallow water super-intensive stacked raceway system. The experiment was run in eight tanks on levels 3 and 4. Water Depth was maintained 12 cm above the crest, 20 cm above the edges, and at an average depth of 16 cm. Clear Water RAS was used and tanks were stocked at 312 shrimp/tank at an average size of 10.5 g. Emphasis was put on optimizing survival over growth.

Daily Activities

- Sand filters in bio-filtration rooms will be backflushed each morning (8:00 AM)
- Bio-filtration settling sumps will be siphoned each morning (8:20 AM)
- Incoming sea water should be checked for flow each morning (8:00 AM)
- Raceway settling sumps will be siphoned each morning (8:40AM)
- Raceways will be examined along their entire length for mortality, feed accumulation, bio-fouling, or any other potential hindrances to optimal growth each morning (8:50 AM)
- Each water inlet will be checked for flow (9:10 AM)
- Dissolved oxygen, Temperature, pH, and Salinity be recorded for each raceway (9:30 AM), and heaters should be adjusted accordingly
- Water quality will be checked in each tank with test strips and values should be recorded (9:45 AM), and water should be exchanged accordingly
- Remaining feed pellets should be assessed so feed amounts can be prepared (1:00 PM)
- Feed will be added to the automatic feeders once daily (1:30 PM)

Activation of Bio-filter

- Bio-filters were activated by adding 200 mL Fritzyme TurboStart Nitrifying Bacteria to each bio-filtration system 3 days and 2 days before stocking

Water Exchange

- Re-circulating exchange rate will be 1 gpm, or 929% per day
- New water will be added at .15 gpm to make up for evaporation.
- Water exchanges will be done by removing flow restrictors from the incoming seawater line in the bio-filtration system along with the flow restrictor inside the raceway tanks of the corresponding stack for 3 hours

Water Temperature

- Water Temperature will be kept between 31 and 32.5ºC at all times by adjustment of the pneumatic water heaters located above the door to the bio-filtration rooms. To adjust the heat down .5ºC, loosen the black circular dial one full turn. To adjust upward, tighten the dial one full turn.

Feeding

- Raceways A3, A4, B3 and B4 will be fed Standard Reference Diet
- Raceways C3, C4, D3, and D4 will be fed Zeigler Floating Feed
  - Week 1
    - Day 1: Feed for 1 g/week per shrimp at an FCR of 1.5
    - Day 2: Feed for 1.5 g/week per shrimp at an FCR of 1.5
    - Days 3-7: Feed for 2 g/week per shrimp at an FCR of 1.5
  - Weeks 2-4
    - Remaining Days: Feed for 2.3 g/week per shrimp at an FCR of 1.5
    - Adjust up or down by increments of 20 g daily based on feed consumption
    - If >99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will be increased
    - If 90-99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will remain the same
    - If >10% of feed is not consumed (floating or accumulated in tank) after 24 hours, feed amount will be decreased
    - Feed amount will be recorded daily
    - If significant mortality(>5 shrimp) is seen when siphoning, feed will not be administered until mortality ceases
- Recommended Feed amounts should be changed to reflect mortality

Water Quality

- Dissolved Oxygen, Salinity, and Temperature will be checked with the YSI meter and recorded onto the provided data sheet
- Samples should be analyzed for TAN, NO_2, NO_3, pH and Alkalinity using test strips and parameters should be recorded daily

Water Quality Parameter Level and Maintenance Strategies		
Parameter	**Optimum Range**	**Maintenance Strategy**
Dissolved Oxygen	4.5+ mg/L	Adjust Air Valves
Temperature	31-32.5ºC	Adjust Pneumatic Gauge
TAN	Below 3.0 ppm	Water Exchange
NO_2	Below 3.0 ppm	Water Exchange
NO_3	Below 200 ppm	Water Exchange

Alkalinity	Above 150 ppm	Add $NaHCO_3$
pH	7.5-8	Add $NaHCO_3$

Mortality

- Mortality will be recorded as # shrimp daily for each tank
- If mortality is seen, the entire tank should be examined thoroughly for additional dead shrimp and possible causes of mortality

Sampling

- Sampling will be done on Mondays, Wednesdays, and Fridays
- Done by netting (green nets with aluminum handles) each tank once and collecting as many shrimp as possible
- Shrimp should be weighed and counted and an average weight should be obtained and recorded for each tank

Results

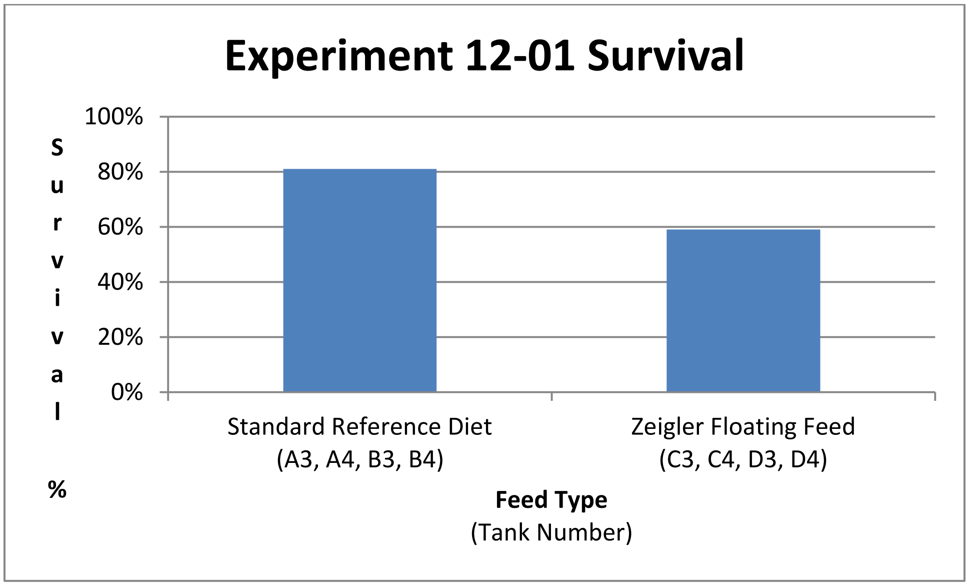


Figure 7. 12-01 Survival

Experiment 12-01 showed that survival was consistently better for tanks fed standard reference diet than in tanks fed the Zeigler floating feed. After this experiment, this particular batch of Zeigler was deemed inadequate and no longer used in raceway experiments. The new water addition of .15 gpm did not add enough new water to the system to keep water quality at desired levels, so this factor was increased in later experiments. Water quality parameters borrowed from experiments with nursery shrimp proved more successful at having higher survival.

5. Rwy 12-02

Brinson A. Lingenfelter

6-12-2012

The objective of Rwy 12-02 was to define the standard operating procedures for 4-week growout periods in the shallow water super-intensive stacked raceway system. The experiment was run in 8 tanks on levels 1 and 2. Water Depth was maintained 12 cm above the crest, 20 cm above the edges and at an average depth of 16 cm. Clear Water RAS with the ability to add new water was used and tanks were stocked at 1,500 shrimp/tank at an average size of 1 g. The animals were 8 g each and 3 kg/m² at the end of the 4-week trial. Emphasis was put on optimizing survival first and increasing growth second.

Daily Activities

- Daily checklist should be gone over twice daily (8:00 AM, 4:50 PM)
- Sand filters in bio-filtration rooms will be back-flushed each morning and afternoon (8:20 AM, 4:200 P.M.)
- Bio-filtration settling sumps will be siphoned each morning and afternoon (8:40 AM, 4:40 P.M.)
- Raceway settling sumps will be siphoned each morning and afternoon (8:40AM, 4:20 P.M.)
- Raceways will be examined along their entire length for mortality, feed accumulation, bio-fouling, or any other potential hindrances to optimal growth each morning (8:50 AM)
- Each water inlet should be checked for flow (8:00 AM)
- Dissolved oxygen, Temperature, and Salinity should be recorded for each raceway (9:30 AM), and heaters should be adjusted accordingly
- Water quality should be checked in each tank with test strips and values should be recorded (9:45 AM), and water should be exchanged accordingly
- Remaining feed pellets should be assessed so feed amounts can be prepared (1:00 PM)
- Raceways will be fed once daily (1:30 PM)

Water Exchange

- Re-circulating exchange rate will be 1 gpm, or 929% per day
- New water will be added at .5 gpm to make up for evaporation.
- Water exchanges will be done by removing flow restrictors from the incoming seawater line in the bio-filtration system along with the flow restrictor inside the raceway tanks of the corresponding stack for 3 hours

Water Temperature

- Water Temperature should be kept between 31 and 32.5ºC at all times by adjustment of the pneumatic water heaters located above the door to the bio-filtration rooms. To adjust the heat down .5ºC, loosen the black circular dial one full turn. To adjust upward, tighten the dial one full turn.

Feeding

- Feed will be administered according to the RWY 12-02 Feed Curve
    - When shrimp are in the linear growth phase, feed will be adjusted up or down by increments of 20 g daily based on feed consumption
    - If >99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will be increased
    - If 90-99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will remain the same
    - If >10% of feed is not consumed (floating or accumulated in tank) after 24 hours, feed amount will be decreased
    - Feed amount will be recorded daily
    - If significant mortality(>5 shrimp) is seen when siphoning, feed will not be administered until mortality ceases
    - Recommended Feed amounts should be changed to reflect mortality
- Days 1-4: All Wenger tanks will receive 32% Wenger 0.8 mm sinking feed, All Standard Reference Diet tanks will receive 35% SRD <12/7 sinking feed
- Days 5-8: All Wenger tanks will receive 32% Wenger 1.5 mm sinking feed, All Standard Reference Diet tanks will receive 35% SRD 12/7 sinking feed
- Days 9-28: Wenger tanks will receive their assigned type of 2.0 mm 32% feed and Standard Reference Diet tanks will receive 2.0 mm 35% SRD feed
- Recommended Feed amounts should be changed to reflect mortality

Feed Assignments	
A1 & C2	35% Standard Reference Diet Sinking
A2 & B1	32% Wenger Sinking
B2 & D1	32% Wenger Slow Sinking
C1 & D2	32% Wenger Floating

Water Quality

- Dissolved Oxygen, Salinity, and Temperature should be checked with the YSI meter and recorded onto the provided data sheet

- Samples should be analyzed for TAN, NO_2, NO_3, and Alkalinity using test strips and parameters should be recorded daily

Water Quality Parameter Level and Maintenance Strategies		
Parameter	**Optimum Range**	**Maintenance Strategy**
Dissolved Oxygen	4.5+ mg/L	Adjust Air Valves
Temperature	31-32.5ºC	Adjust Pneumatic Gauge
TAN	Below 3.0 ppm	Water Exchange
NO_2	Below 5.0 ppm	Water Exchange
NO_3	Below 200 ppm	Water Exchange
Alkalinity	Above 150 ppm	Add $NaHCO_3$
pH	7.5-8	Add $NaHCO_3$

Mortality

- Mortality should be recorded as # shrimp daily for each tank
- If mortality is seen, the entire tank should be examined thoroughly for additional dead shrimp and possible causes of mortality

Sampling

- Sampling will be done on Mondays, Wednesdays, and Fridays
- Done by netting (green nets with aluminum handles) each tank once and collecting as many shrimp as possible
- Shrimp should be weighed and counted and an average weight should be obtained and recorded for each tank

RWY 12-02 Brinson Lingenfelter 6-10-12
Feed curve for 2 feeds

Edit cells highlighted in yellow. Calculation of correction for different stocking weights is hidden in columns T through Y.

Growth trial	Stocking date	Culture tank	Stocking weight (g)	FCR	Days	Number Stocked		Survival/ day (%)		stocking day correction		Feed	SRD 35%	Wenger 32%
												Moisture	10%	10%
RWY 12-02	06/13/12		1.0000	1.50	28	1500		100		27		Dry matter	90%	90%

Edit cell highlighted in blue. Other cells will adjust.

day	date	weight (g)	weight gain (g)	FCR	Number of shrimp removed	Number of shrimp remaining	Feed: SRD 35% feed based on FCR %	Feed: SRD 35% feed based on FCR (g/tank)	Feed: SRD 35% feed adjustment %	Feed: SRD 35% feed adjustment (g/tank)	Feed: SRD 35% total feed (g/tank)	feed crumble size	Feed: Wenger 32% based on FCR %	Feed: Wenger 32% based on FCR (g/tank)	Feed: Wenger 32% feed adjustment %	Feed: Wenger 32% feed adjustment (g/tank)	Feed: Wenger 32% total feed (g/tank)	feed crumble size
0	06/13/12	0.9605	0.1100	1.50		1500	100%	275.00	0%	0.00	275.00	18/14	100%	275.00	0%	0.00	275.00	0.8 mm
1	06/14/12	1.0701	0.1200	1.50		1500	100%	300.00	0%	0.00	300.00	18/14	100%	300.00	0%	0.00	300.00	0.8 mm
2	06/15/12	1.1880	0.1300	1.50		1500	100%	325.00	0%	0.00	325.00	18/14	100%	325.00	0%	0.00	325.00	0.8 mm
3	06/16/12	1.3143	0.1400	1.50		1500	100%	350.00	0%	0.00	350.00	18/14	100%	350.00	0%	0.00	350.00	0.8 mm
4	06/17/12	1.4495	0.1500	1.50		1500	100%	375.00	0%	0.00	375.00	18/14	100%	375.00	0%	0.00	375.00	0.8 mm
5	06/18/12	1.5937	0.1600	1.50		1500	100%	400.00	0%	0.00	400.00	14/12	100%	400.00	0%	0.00	400.00	1.5 mm
6	06/19/12	1.7474	0.1700	1.50		1500	100%	425.00	0%	0.00	425.00	14/12	100%	425.00	0%	0.00	425.00	1.5 mm
7	06/20/12	1.9107	0.1800	1.50		1500	100%	450.00	0%	0.00	450.00	14/12	100%	450.00	0%	0.00	450.00	1.5 mm
8	06/21/12	2.0841	0.1900	1.50		1500	100%	475.00	0%	0.00	475.00	14/12	100%	475.00	0%	0.00	475.00	1.5 mm
9	06/22/12	2.2677	0.2000	1.50		1500	100%	500.00	0%	0.00	500.00	12/7	100%	500.00	0%	0.00	500.00	2.00 mm
10	06/23/12	2.4620	0.2100	1.50		1500	100%	525.00	0%	0.00	525.00	12/7	100%	525.00	0%	0.00	525.00	2.00 mm
11	06/24/12	2.6671	0.2200	1.50		1500	100%	550.00	0%	0.00	550.00	12/7	100%	550.00	0%	0.00	550.00	2.00 mm
12	06/25/12	2.8835	0.2300	1.50		1500	100%	575.00	0%	0.00	575.00	12/7	100%	575.00	0%	0.00	575.00	2.00 mm
13	06/26/12	3.1113	0.2400	1.50		1500	100%	600.00	0%	0.00	600.00	12/7	100%	600.00	0%	0.00	600.00	2.00 mm
14	06/27/12	3.3510	0.2500	1.50		1500	100%	625.00	0%	0.00	625.00	12/7	100%	625.00	0%	0.00	625.00	2.00 mm
15	06/28/12	3.6027	0.2700	1.50		1500	100%	675.00	0%	0.00	675.00	12/7	100%	675.00	0%	0.00	675.00	2.00 mm
16	06/29/12	3.8669	0.2900	1.50		1500	100%	725.00	0%	0.00	725.00	12/7	100%	725.00	0%	0.00	725.00	2.00 mm
17	06/30/12	4.1437	0.3100	1.50		1500	100%	775.00	0%	0.00	775.00	12/7	100%	775.00	0%	0.00	775.00	2.00 mm
18	07/01/12	4.4336	0.3300	1.50		1500	100%	825.00	0%	0.00	825.00	12/7	100%	825.00	0%	0.00	825.00	2.00 mm
19	07/02/12	4.7367	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
20	07/03/12	5.0535	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
21	07/04/12	5.3841	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
22	07/05/12	5.7290	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
23	07/06/12	6.0883	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
24	07/07/12	6.4625	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
25	07/08/12	6.8517	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
26	07/09/12	7.2564	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
27	07/10/12	7.6767	0.3570	1.50		1500	100%	892.50	0%	0.00	892.50	12/7	100%	892.50	0%	0.00	892.50	2.00 mm
28	07/11/12	8.1131				1500												

Figure 8. 12-02 Feed Curve

Results

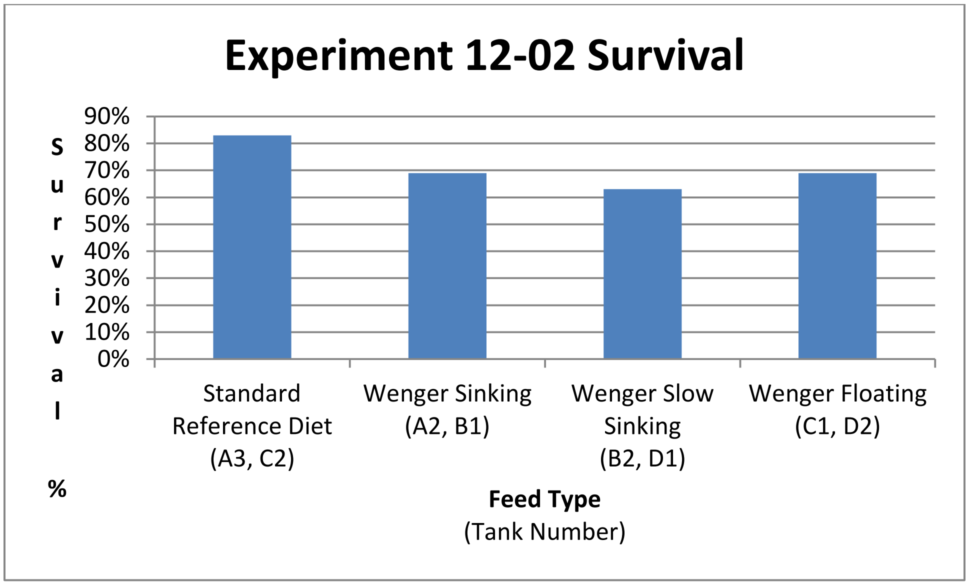


Figure 9. 12-02 Survival

Experiment 12-02 showed a definite trend of the tanks being fed Wenger having lower survival than tanks being fed the standard reference diet. In addition to Wenger feeds being proved unable to match the nutritional value of the Standard Reference Diet, 0.5 gpm of new water added seemed to help the overall water quality of the system and no mass mortality events occurred.

6. Rwy 12-03

Brinson A. Lingenfelter

6-18-2012

The objective of Rwy 12-03 was to define the standard operating procedures for 4-week grow out periods in the shallow water super-intensive stacked raceway system. The experiment was run in 4 tanks on level 4. Water Depth was maintained 12 cm above the crest, 20 cm above the edges, and at an average depth of 16 cm. Clear Water RAS with the ability to add new water will be used and tanks were stocked at 300 shrimp/tank at an average size of 17.3 g. The animals were 26.3 g each and 1.97 kg/m² at the end of the 4-week trial. Emphasis was put on optimizing survival first and increasing growth second.

Daily Activities

- Daily checklist should be gone over twice daily (8:00 AM, 4:50 PM)
- Sand filters in bio-filtration rooms will be back-flushed each morning and afternoon (8:20 AM, 4:20 P.M.)
- Bio-filtration settling sumps will be siphoned each morning and afternoon (8:40 AM, 4:40 P.M.)
- Raceway settling sumps will be siphoned each morning and afternoon (8:40AM, 4:20 P.M.)
- Raceways will be examined along their entire length for mortality, feed accumulation, bio-fouling, or any other potential hindrances to optimal growth each morning (8:50 AM)
- Each water inlet should be checked for flow (8:00 AM)
- Dissolved oxygen, Temperature, and Salinity should be recorded for each raceway (9:30 AM), and heaters should be adjusted accordingly
- Water quality should be checked in each tank with test strips and values should be recorded (9:45 AM), and water should be exchanged accordingly
- Remaining feed pellets should be assessed so feed amounts can be prepared (1:00 PM)
- Raceways will be fed once daily (1:30 PM)

Water Exchange

- Re-circulating exchange rate will be 1 gpm, or 929% per day
- New water will be added at .5 gpm to make up for evaporation.
- Water exchanges will be done by removing flow restrictors from the incoming seawater line in the bio-filtration system along with the flow restrictor inside the raceway tanks of the corresponding stack for 3 hours

Water Temperature

- Water Temperature should be kept between 31 and 32.5ºC at all times by adjustment of the pneumatic water heaters located above the door to the bio-filtration rooms. To adjust the heat down .5ºC, loosen the black circular dial one full turn. To adjust upward, tighten the dial one full turn.

Feeding

- Feed will be administered according to the RWY 12-03 Feed Curve
    - When shrimp are in the linear growth phase, feed will be adjusted up or down by increments of 20 g daily based on feed consumption
    - If >99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will be increased
    - If 90-99% of feed is consumed (not floating or accumulated in tank) after 24 hours, feed amount will remain the same
    - If >10% of feed is not consumed (floating or accumulated in tank) after 24 hours, feed amount will be decreased
    - Feed amount will be recorded daily
    - If significant mortality(>5 shrimp) is seen when siphoning, feed will not be administered until mortality ceases
    - Recommended Feed amounts should be changed to reflect mortality
- Days 1-28: All Wenger tanks will receive 32% Wenger 2.0 mm sinking feed, All Standard Reference Diet tanks will receive 35% SRD 2.0 mm sinking feed
- Recommended Feed amounts should be changed to reflect mortality

Feed Assignments	
A4	35% Standard Reference Diet Sinking
B4	32% Wenger Sinking
C4	32% Wenger Slow Sinking
D4	32% Wenger Floating

Water Quality

- Dissolved Oxygen, Salinity, and Temperature should be checked with the YSI meter and recorded onto the provided data sheet
- Samples should be analyzed for TAN, NO_2, NO_3, and Alkalinity using test strips and parameters should be recorded daily

Water Quality Parameter Level and Maintenance Strategies		
Parameter	**Optimum Range**	**Maintenance Strategy**
Dissolved Oxygen	4.5+ mg/L	Adjust Air Valves
Temperature	31-32.5ºC	Adjust Pneumatic Gauge
TAN	Below 3.0 ppm	Water Exchange
NO_2	Below 5.0 ppm	Water Exchange
NO_3	Below 200 ppm	Water Exchange
Alkalinity	Above 150 ppm	Add $NaHCO_3$
pH	7.5-8	Add $NaHCO_3$

Mortality

- Mortality should be recorded as # shrimp daily for each tank
- If mortality is seen, the entire tank should be examined thoroughly for additional dead shrimp and possible causes of mortality

Sampling

- Sampling will be done on Mondays, Wednesdays, and Fridays
- Done by netting (green nets with aluminum handles) each tank once and collecting as many shrimp as possible
- Shrimp should be weighed and counted and an average weight should be obtained and recorded for each tank

RWY 12-03 Brinson Lingenfel ######

Feed curve for 2 feeds

Edit cells highlighted in yellow. Calculation of correction for different stocking weights is hidden in columns T through Y.

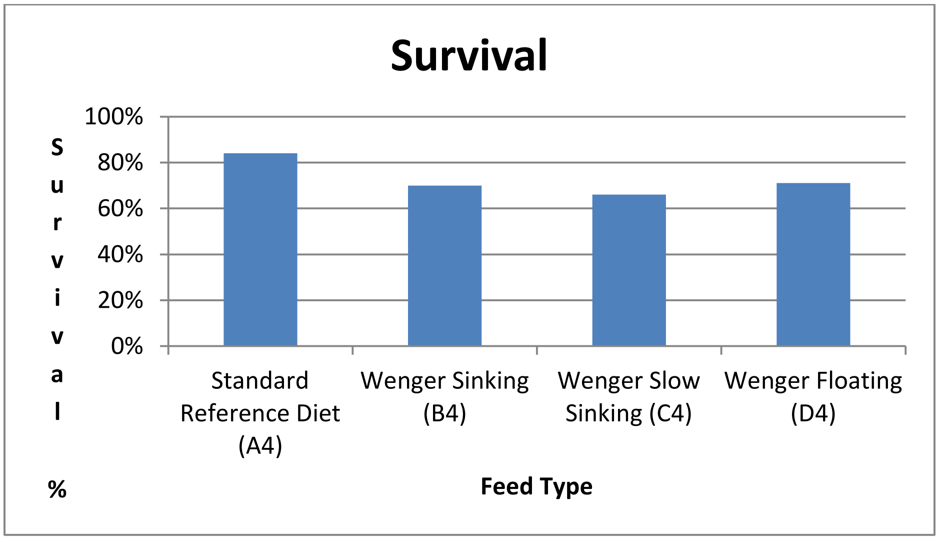
Growth trial	Stocking date	Culture tank	Stocking weight (g	FCR	Number Days	Number stocke		Survival/ day (%)		stocking day correction		Feed	RD 35	Wenger 32%
												Moisture	10%	10%
12-03	06/18/12		17.3	1.50	28	300		100		27		Dry matte	90%	90%

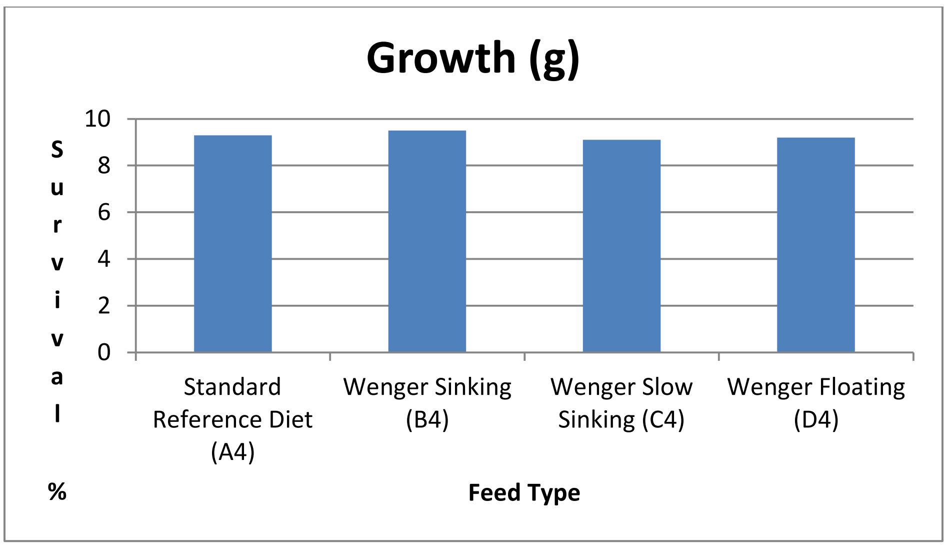
Edit cell highlighted in blue. Other cells will adjust.

day	date	weight (g)	weight gain (g)	FCR	ber of sh mov	ber of sh maini	Feed: SRD 35% feed based on FCR %	feed based on FCR (g/tank)	eed adjustmen %	eed adjustmen (g/tank)	total feed (g/tank)	feed rumble size	Feed: Wenger 32% ed based on FC %	ed based on FC (g/tank)	ed adjustme %	ed adjustme (g/tank)	otal fee (g/tank)	feed rumbl ze (mn
0	06/18/12	17.3000	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	275.00	0%	0.00	275.00	2.00
1	06/19/12	17.6570	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	300.00	0%	0.00	300.00	2.00
2	06/20/12	18.0140	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	325.00	0%	0.00	325.00	2.00
3	06/21/12	18.3710	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	350.00	0%	0.00	350.00	2.00
4	06/22/12	18.7280	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	375.00	0%	0.00	375.00	2.00
5	06/23/12	19.0850	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	400.00	0%	0.00	400.00	2.00
6	06/24/12	19.4420	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	425.00	0%	0.00	425.00	2.00
7	06/25/12	19.7990	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	450.00	0%	0.00	450.00	2.00
8	06/26/12	20.1560	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	475.00	0%	0.00	475.00	2.00
9	06/27/12	20.5130	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	500.00	0%	0.00	500.00	2.00
10	06/28/12	20.8700	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	525.00	0%	0.00	525.00	2.00
11	06/29/12	21.2270	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	550.00	0%	0.00	550.00	2.00
12	06/30/12	21.5840	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	575.00	0%	0.00	575.00	2.00
13	07/01/12	21.9410	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	600.00	0%	0.00	600.00	2.00
14	07/02/12	22.2980	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	625.00	0%	0.00	625.00	2.00
15	07/03/12	22.6550	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	675.00	0%	0.00	675.00	2.00
16	07/04/12	23.0120	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	725.00	0%	0.00	725.00	2.00
17	07/05/12	23.3690	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	775.00	0%	0.00	775.00	2.00
18	07/06/12	23.7260	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	825.00	0%	0.00	825.00	2.00
19	07/07/12	24.0830	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	892.50	0%	0.00	892.50	2.00
20	07/08/12	24.4400	0.3570	1.50		300	100%	178.50	0%	0.00	178.50	12/7	100%	892.50	0%	0.00	892.50	2.00

Figure 10. 12-03 Feed Curve

Results





Figures 11 & 12. 12-03 Survival and Growth

Experiment 12-03 showed results similar to those of 12-02 in that the Standard Reference Diet distinctly outperformed the Wenger diet. Water quality remained very stable throughout this experiment and good growth was shown in all raceways. The growth numbers are somewhat skewed due to lower survival in Wenger fed tanks, but all tanks showed growth above 2 g/ week. This experiment provides a good baseline going forward for an adequate nutritional feed to go forward and defines the process for how to correctly operate the stacked raceways.

CONCLUSIONS

Results from the stacked raceway system were favorable for shrimp growing from size PL_{10} to 8-9g. Survival from multiple experiments approached 100% and was consistent in that range. During the growout phase of shrimp from 8-9g to 25-26g, lower and inconsistent survivals were seen, averaging around 75%. The lower survival of larger shrimp was thought to be a result of inadequate feeds during testing of this size shrimp, along with stricter water quality requirements for shrimp during this life stage. The stacked raceway system showed a great deal of promise and the process outlined in this manual will allow the system to be run efficiently and with high profitability once the maturation grow out process is more clearly defined in upcoming experiments. In the meantime, the success in growout of smaller shrimp up to 8-9g can presently be applied commercially to produce shrimp of that size at a consistent high production level.

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