The Texas A&M AgriLife Biofloc Systems

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Texas A&M AgriLife Research Mariculture Lab at Flour Bluff, Corpus Christi, Texas

Aquaculture America 2014 February 9-12, 2014 Seattle, Washington
Structures

- 6 Ponds
- 7.5 m³ tanks - 24
- 0.85 m³ tanks - 84
- 3 Greenhouses
  - RWs 40 m³ - 6
  - RWs 100 m³ - 2
  - Circular 15 m³ - 2
40 m³ RWs - Greenhouse

- 6 shallow (0.45 m) RWs 68.5 m²
- EPDM lined (1 mm thickness)
- Eighteen 2” Airlift pumps
- Six 0.9 m air diffusers
- Air-blowers
- Center partition
- Bottom manifold with injectors
- 2 hp pump
- Foam Fractionator & Settling Tank
- Air/O₂ fed Venturi
- Cyclone Filter*
40 m³ RWs - Greenhouse

FACILITY HEATING AND LIGHT CONTROL:
- 3 Fans
- 3 Exhausts
- Shade cloth (83% light reduction)
40 m³ RWs - Greenhouse

BIOFLOC & SOLIDS CONTROL (FOAM FRACTIONATOR):
40 m³ RWs - Greenhouse

BIOFLOC & SOLIDS CONTROL (CYCLONE & SETTLING TANKS):

- Solids spun out of suspension
- Flow: 50-500 L/min
- Min. Pressure: 50 psi
40 m³ RWs - Greenhouse

VENTURI & O₂ SUPPLY:

- Flow meter, Venturi and O₂ supply
- O₂ Flow meter
- Venturi
- O₂ supply
- Water flow
- O₂ Cylinders & LOX
Factors to be considered: Diameter of the air delivery pipe system, ALP size and type, Filter pipe socket, size of the Venturi injector and the diameter of the water delivery pipes.
40 m³ RWs – Greenhouse
RECIRCULATION SYSTEM:

- Intake Point
- Nozzle
- Air diffusers
- Airlift Pumps
- Return Point
- Partition
- Nozzle
40 m³ RWs - Greenhouse

FEEDING SYSTEM:

- Six 24 h belt feeders
- Monitoring overfeeding
- Avoiding DO fluctuations
- Loading 1/day – saving time
40 m³ RWs - Greenhouse

MONITORING SYSTEM:

Daily:
- DO (mg/L)
- Temperature (°C)
- Oxygen saturation (%)
- pH
- Salinity (ppt)

Continuous:
- DO (mg/L) / alarm activation
- Temperature (°C)
- Remote monitoring
- Feed delivery control (in progress)
40 m³ RWs - Greenhouse

SAFETY SYSTEMS:

- Traps › › Predators
- Walls (Physical barrier)
- Electric Fence
- Motion Sensor
40 m³ RWs - Greenhouse

DRAINAGE PIPE:

- Vertical Intake
- Horizontal Intake

[Images of drainage pipes in a greenhouse setting, labeled with 'Vertical Intake' and 'Horizontal Intake']
40 m³ RWs - Greenhouse

ELECTRICITY:

Remote Power and Air Monitoring System

Air Pressure Sensor

Backup Generator
40 m³ RWs - Greenhouse

ACCUMULATION OF BIOFLOC ON THE SURFACE

Mixing the floating biofloc

Use of water jet
40 m³ RWs - Greenhouse

HARVEST:

- Catching shrimp with dip nets
- Shrimp into harvest buckets
- Weighing buckets of shrimp

Important issues:

- Timing water draining
- Shrimp over crowding in basket
- Sampling
100 m³ RWs - Greenhouse

- Two 100 m³ RWs
- No Air Blowers
- Nozzles
- Two 2 HP Pump
- Foam Fractionators
- Settling Tanks
- Digester*
- Fans
100 m³ RWs - Greenhouse

WATER FLOW:

= Nozzles
= Water Flow

2 hp

34 M

3 M

2 hp

WATER FLOW: 100 m³ RWs - Greenhouse
100 m$^3$ RWs - Greenhouse

HARVEST:
Ammonia Production by Shrimp

1. Use of software such as AquaCalc

2. Use of a generic formula

$100\,\text{g (F)} \times 35\%\,\text{CP} = 35\,\text{g (P)} \times 6.25\,(\text{CF}) = 5.6\,\text{g (N)} \times 50\% = 2.8\,\text{g TAN}$
Ammonia Removal in Aquaculture

- Unlike nitrifying bacteria that produce nitrite and nitrate, heterotrophic bacteria incorporate ammonia nitrogen directly into microbial biomass.
- When using 35% CP feed, only 1/3 of the dissolved organic carbon required by the heterotrophic bacteria is available from the feed.
- This means that additional organic C must be added for the heterotrophic bacteria to use all available ammonia generated by the shrimp.
Autotrophic Nitrification

- Unless animals are fed a low-protein (~12%) feed, biofloc systems tend to favor autotrophic (nitrifying) bacteria over heterotrophic bacteria when there is no supplementation of organic carbon.

- This leads to a greater loss of alkalinity and a higher accumulation of nitrate.

- Removing excess nitrate is one of the main reasons for exchanging water in otherwise closed systems.
Heterotrophic Systems

- Heterotrophic bacterial growth is affected by the system’s C/N ratio, temperature, DO, pH, and salinity.
- Increase in microbial biomass production is 40 times greater than the biomass generated from the nitrification process, and consumption of O$_2$ is also much higher.
- CO$_2$ production of heterotrophic floc also is higher than that of autotrophic nitrifiers.
Why Operate a Mixotrophic System?

- Although adding alkalinity is required for the nitrifying bacteria to work properly, some of it can be recovered if the system has a denitrification loop.
- If operated as a fully heterotrophic system, a greater effort and additional resources are required to control bacterial biomass, in particular, the system requires regular supplementation of dissolved organic carbon and much more oxygenation.
- A mixotrophic system, however, balances between the two extreme bacterial regimes to incorporate some the advantages of both.
The WQ Map  (Water-quality Map)

- Simplifies routine water-quality management
- Has the latest chemical formulae under-the-hood
- Alkalinity is scaled along on the $y$-axis
- Dissolved Inorganic Carbon, along the $x$-axis
- pH appears as a family of straight lines
- pH lines change with temp & salinity
- Lines of lower pH are on the right of the WQ Map
- Buffering is greater where pH lines are farther apart
Tank: Your Tank ID
Date: Wed 01/22/2014
Volume: 150.0 m³
Temp: 28.0 °C
Salinity: 34.5 PSU

Ionic

TAN: 0.10 mg/l
[NH₃]: 0.0125 mg/l

[C₅]: 10 mg/l

Map High [NH₃] Region
Map High [C₅] Region

Map Scale

pH Bounds
Min: 7.4  Max: 8.1

[Alk] Bounds
Min: 1.5  Max: 3.5

Dissolved Inorganic Carbon

pH 9.0
pH 7.0
pH 6.0

Alkalinity

DIC (mmole/kg)
WQ Map - The Green & Danger Zones

- **The Green Zone** defines a preferred pH - [Alk] regime
  *(illustrated: pH 7.4-8.1 & [Alk] 75-175 ppm CaCO₃)*

- **CO₂ Danger Zone**
  *(illustrated: [CO₂] ≥ 20 mg/L)*

- **NH₃ Danger Zone**, as a function of (Temp., Sal., pH)
  *(illustrated: [NH₃] ≥ 0.0125 mg/L & TAN 0.2 mg/L)*

- So, the “game” is to keep your system...
  - ...in the Green Zone
  - ...out of the Danger Zones
WQ Map - Adjustment Example #1

- **Enter:** temp: 32 C; salinity: 34 ppt; volume: 40 m³
- **Enter Initial State:** pH 6.7, [Alk] 1.4 meq/L (70 ppm CaCO₃)
- **Enter Target State:** pH 7.4, [Alk] 2.3 meq/L (115 ppm CaCO₃)
- **Choose:** NaHCO₃ (Na bicarbonate) & Na₂CO₃ (Na carbonate)
- **Yellow Zone** -- where you can 'travel' with NaHCO₃ & Na₂CO₃
- **Press:** “Calculate” to get...
  * adjustment path -- how & how fast pH & [Alk] change
  * how much of each reagent to add

  **Ans:** 1.49 kg NaHCO₃
  
  0.97 kg Na₂CO₃
Enter: temp: 32 C; salinity: 34 ppt; volume: 40 m³

Enter Initial State: pH 6.7, [Alk] 1.4 meq/L (70 ppm CaCO₃)

Enter Target State: pH 7.4, [Alk] 2.3 meq/L (115 ppm CaCO₃)

Choose: NaHCO₃ (Na bicarbonate) & NaOH (Na hydroxide)

Yellow Zone -- where you can 'travel' with NaHCO₃ & NaOH

Press: “Calculate” to get...

* adjustment path -- how & how fast pH & [Alk] change
* how much of each reagent to add

Ans: 2.26 kg NaHCO₃
    0.36 kg NaOH
WQ Map - Summary

- Alkalinity adjustments generally change pH, $[\text{CO}_2]$, $\Omega$ (Ca mineral saturation), $[\text{NH}_3]$, & metal toxicity
- The WQ Map can predict changes in water quality resulting from feed additions, nitrification, photosynthesis, & water exchange
- It works for any aquatic system: biofloc systems, flow-through ponds, algae tanks, home aquaria, aquaponic systems, swimming pools
- The WQ Map has been used to adjust water-quality quickly & accurately in the A&M biofloc system
Acknowledgements

- National Sea Grant College Program for funding
- Florida Organic Aquaculture for the cooperation and the commercialization
- Texas A&M AgriLife Research for providing the support for the last 26 years
- Current and former researchers, students and staff members of the Texas A&M AgriLife Research Mariculture Lab for the hard work and dedication
End of Section
Design and Management of Nursery Systems for *Litopenaeus vannamei* Postlarvae

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Operations

PRE-PRODUCTION PROCEDURES:
Water source & conditioning

- Water pumped from the power plant intake canal
- Stored in reservoir (Pond)
- Salinity adjustment (30 ppt)
- Water pumped into raceways
- Water treated with chlorine to reach 5-10 ppm 30 min after application
Operations
PRE-PRODUCTION PROCEDURES:

Organic Carbon

➢ Probiotic + Molasses added before stocking with shrimp
➢ Jumpstart nitrifying bacteria (*FritzZyme 9, AmQuel Plus*), floc inoculation
➢ Treatment maintained post-stockling to keep the biofloc “healthy” (e.g., prevent algal bloom)
Operations
PRE-PRODUCTION PROCEDURES:
PL Transportation, Receiving and Acclimation

- Bags in styrofoam boxes
- Acclimation tanks
- Adjust salinity & temperature
- Some feeding to minimize cannibalism
- Shrimp stocked
- Assessing mortality
Operations

NURSERY

Feeding and feed management
- EZ *Artemia* + Dry feed (<400 µm) - 1\textsuperscript{st} week
  (5 times/day)
- Crumble (<400 µm to 1,200 µm) - 1\textsuperscript{st} 21 days
- Use of intermittent & overall FCR as a tools
- Calculations based on growth, FCR & survival

Growth monitoring
- Select the right mesh & net size to sample
- 50 animals, twice/wk (Individual & Group weight, check morphological structure, behavior, food in digestive system & fouling)
Operations
NURSERY
Daily & Weekly Routines
- Water quality
  - pH, DO, salinity, temperature - Daily
  - Alkalinity, SS, TSS, (VSS), ammonia, nitrite, (nitrate), (phosphate) - At least weekly (not critical)
- Visual observation of shrimp in all RWs - Daily
  - Swimming activity, food in digestive system, disease, fouling, morphological structure
- Dissecting scope and/or compound microscope observations – Twice a week
- Feed management & feeding - Daily
NURSERY

Carbon supplementation factors to consider

- Dissolved oxygen levels in the tank
- Ability to increase DO in the tank
- Concentrations of TAN and Nitrite in the water
  - Nitrite is low and TAN starts to increase (3-5 mg/L)
  - Both Nitrite and TAN start to increase (3-5 mg/L)

To convert 1 g of TAN into heterotrophic bacteria biomass you need 6 g of organic carbon
NURSERY

Example use of organic carbon from molasses:
40 m³ RW with 4 mg/L TAN in the water

1,000 ml molasses = 1,300 g = 312 g C (1,300 x 24%)

TAN in the tank: 4 x 40,000 = 160 g

C needed: 160 x 6 = 960 g

Molasses needed: 960 / 312 = 3.08 L
NURSERY
Supplemental feed

- Start with wet & dry feed
- Increase feed particle size over time (400-600, 600-800, 850-1,200 µm)

**EZ Artemia – Wet feed**

<table>
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<tr>
<th>Component</th>
<th>Value</th>
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<tbody>
<tr>
<td>Crude Protein</td>
<td>&gt; 51.0 %</td>
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<tr>
<td>Crude Fat</td>
<td>&gt; 17.0 %</td>
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<td>Crude Fiber</td>
<td>&lt; 3.7 %</td>
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<tr>
<td>Moisture</td>
<td>&lt; 0.0 %</td>
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**< 400 µm – Dry feed**

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<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein</td>
<td>&gt; 50.0 %</td>
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<tr>
<td>Crude Fat</td>
<td>&gt; 15.0 %</td>
</tr>
<tr>
<td>Crude Fiber</td>
<td>&lt; 1.0 %</td>
</tr>
<tr>
<td>Moisture</td>
<td>&lt; 10.0 %</td>
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<tr>
<td>Ash</td>
<td>&lt; 7.5 %</td>
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</tbody>
</table>
Operations

NURSERY

Shrimp sampling, health & diseases

- Shrimp are collected twice a week from all RWs
- Shrimp are collected from 3 or more different locations within each RW
- Water chilled with ice is used to slow-down swimming activities
- Group and individual weight
- Inspect morphological aspects using microscopy
- Shrimp behavior & general appearance observed with emphasis on fouling & gut fullness
# Feed and feed management for 40 m³ Nursery RWs stocked at 650 PL/m³ - Texas A&M AgriLife Research

| EST TEMP | DAY | STAGE | WEIGHT | GAIN % | GAIN g | SURVIVAL % | NUMBER ANIMALS | BIOMASS kg | FCR DAILY | FCR CUMULATIVE | FEED FREQUENCY | TOTAL FEED Grams | FEEDDAY Grams Dry Wt. | EZ Art (%) | TotalDay Wet wt | Dry Diet+ (%) | Grams TotalDay Wet wt | TYPE | TOTAL APPX |
|----------|-----|-------|--------|--------|--------|------------|--------------|------------|-----------|----------------|----------------|----------------|----------------|--------------|----------------|--------------|----------------|----------------|----------------|----------------|----------|-----------|
| 24.5     | 1   | PL 12 | 0.0015 | 26     | 100.0  | 266,000    | 0.43         | 0.8       | 24X       | 89             | 89.2           | 50%            | 165.2         | 50%          | 44.6          | EZ ART, RW <400, Feed 3X |
| 24.5     | 2   | PL 13 | 0.0019 | 25     | 0.0004 | 97.0       | 277,420     | 0.52       | 0.8       | 24X           | 194            | 104.9          | 50%            | 194.2        | 50%           | EZ ART, RW <400, Feed 3X |
| 24.5     | 3   | PL 14 | 0.0024 | 25     | 0.0005 | 96.7       | 276,627     | 0.65       | 0.8       | 24X           | 325            | 130.7          | 50%            | 242.0        | 75%           | EZ ART, RW <400, Feed 3X |
| 24.5     | 4   | PL 15 | 0.0030 | 24     | 0.0006 | 96.4       | 275,837     | 0.81       | 0.8       | 24X           | 481            | 156.4          | 25%            | 144.8        | 100%          | EZ ART, RW <400, Feed 3X |
| 24.5     | 5   | PL 16 | 0.0037 | 24     | 0.0007 | 96.2       | 275,049     | 1.01       | 0.8       | 24X           | 675            | 193.4          | 25%            | 179.1        | 100%          | EZ ART, RW <400, Feed 3X |
| 24.5     | 6   | PL 17 | 0.0045 | 24     | 0.0009 | 95.9       | 274,263     | 1.25       | 0.8       | 24X           | 914            | 238.1          | 25%            | 221.4        | 100%          | EZ ART, RW <400, Feed 3X |
| 24.5     | 7   | PL 18 | 0.0056 | 24     | 0.0011 | 95.6       | 273,479     | 1.54       | 0.8       | 24X           | 1,209         | 295.6          | 10%             | 109.5        | 100%          | EZ ART, RW <400, Feed 3X |
| 27.4     | 8   | PY 19  | 0.0070 | 24     | 0.0014 | 95.3      | 272,698     | 1.90       | 0.8       | 24X           | 1,575         | 386.5          | 10%             | 135.4        | 100%          | EZ ART, RW <400, Feed 3X |

**Feed and feed management for 40 m³ Nursery RWs**

**GAIN**

**GAIN**

**SURVIVAL**

**NUMBER ANIMALS**

**BIOMASS**

**FCR DAILY**

**FCR CUMULATIVE**

**FEED FREQUENCY**

**TOTAL FEED Grams**

**FEEDDAY Grams Dry Wt.**

**EZ Art (%)**

**TotalDay Wet wt**

**Dry Diet+ (%)**

**Grams TotalDay Wet wt**

**TYPE**

**TOTAL APPX**

---

**Note:** The table above provides a detailed breakdown of feed and feed management for 40 m³ Nursery RWs stocked at 650 PL/m³, including parameters such as weight, gain, survival, number of animals, biomass, FCR daily, FCR cumulative, feed frequency, total feed grams, feedday grams dry wt, EZ art, total day wet wt, dry diet+, grams total day wet wt, type, and total appx.
Operations

NURSERY

WQ sampling -- and indicators to watch for

- Ammonia and Nitrite concentration
- Solids Accumulation - Optimum: TSS (250-350 mg/L) & SS (10-14 mL/L)
- Turn on settling tanks, FF or cyclone filters & closely monitor solids concentrations until under control
- TSS vs. SS readings
- Maintain $O_2 > 4$ mg/L (control by adjusting air flow in the airlift pumps and the air diffusers)
- Use pure $O_2$, when needed
- Low DO may indicate overfeeding, high level of solids or another water quality problem
Operations

NURSERY

Alkalinity, pH control

- **Target pH:** 7.4-7.6; **Alkalinity:** 140-160 mg/L
- **Alkalinity** - Bicarbonate
- **pH** – NaOH
- **Alkalinity/pH** – Soda Ash
- All of these chemicals are added carefully to avoid drastic changes in pH
- Dripping is the method of choice
Handling WQ emergencies

- Lost power supply - back-up generator
- pH decreasing - add soda ash or NaOH
- Alkalinity decreasing - add soda ash or bicarbonate
- TSS or SS increasing - turn on FF, cyclones or ST
- Ammonia increasing - add organic C such as molasses
- Nitrite increasing - add nitrifying bacteria or decrease feed quantity and/or suspend feeding
Operations
NURSERY
Handling WQ emergencies (40 m³ RWs)
- Shrimp swimming close to the surface - check DO
- Shrimp with white tails – check DO and increase its level if needed
- To increase DO the following actions:
  - Increase air flow to airlift pumps & air diffusers
  - Supply oxygen through the Venturi
  - Reduce solids (FF, ST, Cyclone), suspend / decrease rations
Operations
NURSERY
Summary of results 1998-2013

- Shift from HDPE to EPDM liners (be aware of toxicity issues)
- Exposure to high NO$_2$-N levels (up to 26 mg/L) for 2 wks had no adverse effect on shrimp performance in the nursery or subsequent grow-out phase
- Significantly higher nitrate levels in high-protein diet
- Molasses - enhance bacterial floc development, effective in controlling ammonia but not nitrite
- DO monitoring system - an excellent tool to manage DO & feed inputs, reduce shrimp stress & WQ deterioration
- *L. vannamei* can tolerate high levels of ammonia ($\leq 26$ mg/L) & nitrite ($\leq 35$ mg/L) with good growth, survival & excellent health at 30 ppt salinity in the presence of biofloc & under no water exchange
NURSERY

Summary of results 1998-2013

- Nursery of PL at high densities in biofloc dominated water didn’t result in reduced growth in the GO phase.
- Using matured water for inoculation is beneficial in avoiding increase of ammonia & nitrite when using virgin seawater.
- Juveniles from these systems can be transferred into GO ponds with minimal losses.
- Applications of organic carbon should be started if TAN increases above 3 mg/L (see earlier slide).
### NURSERY

#### Summary of results 1998-2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>PL/m²</th>
<th>PL/m³</th>
<th>Wt₀ (mg)</th>
<th>Days</th>
<th>Wtₙ (g)</th>
<th>Yield (kg)/m²</th>
<th>Yield (kg)/m³</th>
<th>Sur. (%)</th>
<th>FCR</th>
<th>Exc. (%/d)</th>
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<tbody>
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<td>1,000</td>
<td>1,700</td>
<td>1</td>
<td>35</td>
<td>0.70</td>
<td>0.61</td>
<td>1.04</td>
<td>86.8</td>
<td>0.61</td>
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<td>1,000</td>
<td>1,700</td>
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<td>0.42</td>
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<th>Sur. (%)</th>
<th>FCR</th>
<th>Exc. (%/d)</th>
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<td>5,800</td>
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<td>15</td>
<td>0.07</td>
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<td>0.52</td>
<td>0.8</td>
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<td>3,390</td>
<td>5,800</td>
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<td>0.15</td>
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<td>0.57</td>
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<td>34</td>
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<td>0.87</td>
<td>1.49</td>
<td>100</td>
<td>0.80</td>
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<td>5,550</td>
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<td>0.23</td>
<td>0.75</td>
<td>1.28</td>
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## NURSERY

Summary of results 1998-2013

### L. vannamei 2000 (1.1%/d exchange)

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<th>PL/m²</th>
<th>PL/m³</th>
<th>Wt₀ (mg)</th>
<th>Days</th>
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<td>2,200</td>
<td>3,770</td>
<td>0.8</td>
<td>50</td>
<td>1.23</td>
<td>2.70</td>
<td>4.62</td>
<td>97</td>
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<tr>
<td>2,200</td>
<td>3,770</td>
<td>0.8</td>
<td>50</td>
<td>1.1</td>
<td>2.76</td>
<td>4.73</td>
<td>106</td>
</tr>
</tbody>
</table>

### L. vannamei Intensive Nursery Inland Woods Bros., AZ

<table>
<thead>
<tr>
<th>PL/m²</th>
<th>PL/m³</th>
<th>Wt₀ (mg)</th>
<th>Days</th>
<th>Wt₉ (g)</th>
<th>Yield (kg)/m³</th>
<th>Sur. (%)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>19,200</td>
<td>12,700</td>
<td>2.5</td>
<td>34</td>
<td>0.1</td>
<td>2.34</td>
<td>1.54</td>
<td>100</td>
</tr>
<tr>
<td>20,400</td>
<td>13,500</td>
<td>2.5</td>
<td>35</td>
<td>0.09</td>
<td>2.1</td>
<td>1.34</td>
<td>100</td>
</tr>
</tbody>
</table>

Four RWs: 98 m²; 148 m³; Salinity: 1.8-2.6 ppt
### NURSERY

**Summary of results 1998-2013**

**L. vannamei 2002**

<table>
<thead>
<tr>
<th>Water Treat.</th>
<th>PL /m³</th>
<th>Wt₀ (mg)</th>
<th>Days</th>
<th>Wtₚ (g)</th>
<th>Yield kg/m³</th>
<th>Sur. (%)</th>
<th>Water Ex (%/d)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bead¹</td>
<td>3,780</td>
<td>0.6</td>
<td>74</td>
<td>0.65</td>
<td>2.42</td>
<td>96.3</td>
<td>1.35</td>
<td>1.70</td>
</tr>
<tr>
<td>RSF²</td>
<td>6,540</td>
<td>0.6</td>
<td>74</td>
<td>0.85</td>
<td>5.26</td>
<td>100.1</td>
<td>0.47</td>
<td>1.09</td>
</tr>
<tr>
<td>FF³</td>
<td>5,010</td>
<td>0.6</td>
<td>74</td>
<td>0.69</td>
<td>3.18</td>
<td>97.8</td>
<td>2.06</td>
<td>1.50</td>
</tr>
</tbody>
</table>

¹Bead Filter-BF, ²Pressurized Rapid Sand Filter, ³Foam Fractionator-FF

**L. vannamei 2003**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Wt₀ (mg)</th>
<th>Wtₚ (g)</th>
<th>Yield (kg/m³)</th>
<th>Survival (%)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF-2 ¹</td>
<td>0.6</td>
<td>1.91</td>
<td>7.64</td>
<td>100</td>
<td>0.97 a</td>
</tr>
<tr>
<td>FF-3 ¹</td>
<td>0.6</td>
<td>2.00</td>
<td>6.89</td>
<td>92.4</td>
<td>1.08 a</td>
</tr>
<tr>
<td>WE-1 ²</td>
<td>0.6</td>
<td>1.73 b</td>
<td>3.92 b</td>
<td>55.9</td>
<td>1.64 a</td>
</tr>
<tr>
<td>WE-4 ²</td>
<td>0.6</td>
<td>1.43 b</td>
<td>4.74 b</td>
<td>81.8 a</td>
<td>1.36 a</td>
</tr>
</tbody>
</table>

¹ Raceway operated with FF & 3.35% daily water exchange  
² Raceway operated with no FF using 9.37% daily water exchange
# NURSERY

Summary of results 1998-2013

## L. vannamei 2009

<table>
<thead>
<tr>
<th>Variables</th>
<th>30% CP</th>
<th>40% CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final weight (g)</td>
<td>0.94 ± 0.00</td>
<td>1.03 ± 0.02</td>
</tr>
<tr>
<td>Survival (%)</td>
<td>82.29 ±11.26</td>
<td>84.13 ±6.07</td>
</tr>
<tr>
<td>FCR</td>
<td>0.91 ± 0.05</td>
<td>0.82 ± 0.05</td>
</tr>
<tr>
<td>Yield (kg/m³)</td>
<td>3.70 ± 0.49</td>
<td>4.18 ± 0.23</td>
</tr>
</tbody>
</table>

## L. vannamei 2011

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Wt. (g)</th>
<th>Yield (kg/m³)</th>
<th>Survival (%)</th>
<th>FCR</th>
<th>Water Use (L/kg shrimp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disease R</td>
<td>0.90 a</td>
<td>3.36 a</td>
<td>98.7 a</td>
<td>1.03 a</td>
<td>372 a</td>
</tr>
<tr>
<td>Growth L</td>
<td>0.74 b</td>
<td>3.02 a</td>
<td>100 a</td>
<td>1.17 a</td>
<td>385 a</td>
</tr>
</tbody>
</table>
Acknowledgements

- National Sea Grant College Program for funding
- Florida Organic Aquaculture for the cooperation and the commercialization
- Texas A&M AgriLife Research for providing the support for the last 26 years
- Current and former researchers, students and staff members of the Texas A&M AgriLife Research Mariculture Lab for the hard work and dedication
End of Section
Design and Management of Grow-out Systems for *Litopenaeus vannamei*

Tzachi M. Samocha, Leandro F. Castro and David Prangnell

Texas A&M AgriLife Research Mariculture Lab at Flour Bluff, Corpus Christi, Texas

Aquaculture America 2014 February 9-12, 2014 Seattle, Washington
Operations
GROW-OUT
Stocking/Transfer:

Dip net
- Weighing (biomass!)
- Wet transfer (bio.!!)
- Water transfer (bio.!!)
- Use of oxygen

Drain harvest
- Weighing
- Wet transfer
- Water transfer

Fish pump
- Shrimp counter*
- Weighing
- Wet transfer

* Future plan
Nursery Systems – Juvenile Transfer

Use of fish pump to transfer juvenile shrimp into a secondary greenhouse-enclosed nursery located 800 m away from the primary nursery – Mexico (700K, 70 mg in 30 min)
Operations

GROW-OUT

Daily & weekly operations routine

- **Water quality**
  - pH, DO, salinity, temperature - Daily
  - Alkalinity, SS, TSS, (VSS), ammonia, nitrite, (nitrate), (phosphate) - At least weekly (not critical)

- **Disperse floating mat of biofloc**
  - Steering/mixing (40 m³ & 100 m³ RWs Systems)
  - Use of water jet (40 m³ RWs)
  - Directional flow (100 m³ RWs)
Operations
GROW-OUT
Daily & weekly operations routine

- Visual observation of shrimp in all RWs - Daily
  - Swimming performance, food in digestive system, morphological structure (antennae, legs, gills), size homogenization, disease, fouling
- Feed management and Feeding - Daily
  - Use of dip net to check for feed leftover with emphasis on areas near the feeders
  - Suspend feeding and/or reduce rations
Operations
GROW-OUT
Carbon supplementation
- Avoid algal dominated water
- If water turns green, consider adding molasses to create shading and stimulate heterotrophic bacterial growth
- Carbon should be added gradually to avoid sharp DO decreases
GROW-OUT

Daily Ration Calculations

Assumptions:

- Population size: 100,000 shrimp at stocking
- Assumed growth rate: 2 g/wk
- Assumed FCR: 1.4
- Mortality: 0.5%/wk

Daily Ration at week 8:

\[
100,000 \times 2 \text{ (g/wk)} \times 1.4 \text{ (FCR)} \times 96\% / 7 = 38,400 \text{ g}
\]
**Operations**

**GROW-OUT**

Supplemental feed

- Feed rations are calculated based on previous week feed consumption and expected shrimp growth

<table>
<thead>
<tr>
<th></th>
<th>SI - 35</th>
<th>HI - 35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>7.97 %</td>
<td>8.73 %</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>35.8 %</td>
<td>35.78 %</td>
</tr>
<tr>
<td>Crude Fat</td>
<td>9.86 %</td>
<td>8.72 %</td>
</tr>
<tr>
<td>Crude Fiber</td>
<td>2.69 %</td>
<td>1.92 %</td>
</tr>
<tr>
<td>Ash</td>
<td>11.11 %</td>
<td>9.61 %</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>N/A</td>
<td>37.16 %</td>
</tr>
</tbody>
</table>

- Effect of feed on shrimp performance
Operations
GROW-OUT
Shrimp sampling, health & diseases
- Twice a week
- Selection of dip net and/or cast net
- Check morphological structures – antenna, rostrum, legs, tissues, molting, full gut, eyes, gills, necrosis
- Check shrimp behavior
- Weigh and count shrimp in samples (estimate average weight, biomass, FCR, overall growth, weekly growth)
Operations
GROW-OUT
WQ sampling -- and indicators to watch for

- Overfeeding can decrease DO (accurate feed estimate is very important)
- High TSS concentration increase O$_2$ consumption (use FF, ST & CF to control)
- Water flow through ST: 12 L/min (40 m$^3$ RWs), 20 L/min (100 m$^3$ RWs); CF: 50-500 L/min; FF: use inlet/outlet valves as needed
- SS: 10-14 mL/L
- Adjust flow rates as needed to get the desirable TSS level
GROW-OUT
Indicators to watch for handling WQ emergencies

- Lost power supply - back-up generator
- pH decreasing - add soda ash or NaOH
- Alkalinity decreasing - add soda ash or bicarbonate
- TSS or SS increasing - turn on FF, CF or ST
- Ammonia increasing - add molasses or other organic C
- Nitrite increasing - add nitrifying bacteria or decrease feed quantity / suspend feeding or increase organic C
- Low DO (40 m³): - turn on pure oxygen supply, adjust air flow in ALPs, remove solids or decrease/skip rations; 100 m³ – turn on 2nd pump
## GROW-OUT
Summary of results 2006-2013

**L. vannamei 2006 (94 d, 40 m³ Raceways)**

<table>
<thead>
<tr>
<th>ID</th>
<th>Wt&lt;sub&gt;f&lt;/sub&gt; (g)</th>
<th>Growth (g/wk)</th>
<th>Yield (kg/m³)</th>
<th>Sur. (%)</th>
<th>FCR</th>
<th>New Water (%/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No FF¹</td>
<td>17.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.11&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>85.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.28&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.74&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>No FF¹</td>
<td>17.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.91&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>81.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.34&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.51&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FF²</td>
<td>16.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>93.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.55&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FF²</td>
<td>15.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.26&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.51&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>WE³</td>
<td>17.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.36&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>WE³</td>
<td>17.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>77.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.41&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

¹ RW’s operated w/ molasses & limited water exchange w/o FF; ² RW’s operated w/ molasses & limited water exchange & w FF; ³ RW’s operated with increased water exchange & w/o FF

**L. vannamei 2007 (94 d, 40 m³ Raceways)**

<table>
<thead>
<tr>
<th>ID</th>
<th>Wt&lt;sub&gt;f&lt;/sub&gt; (g)</th>
<th>Growth (g/wk)</th>
<th>Yield (kg/m²)</th>
<th>Yield (kg/m³)</th>
<th>Sur. (%)</th>
<th>FCR</th>
<th>Water Use (L/kg Shrimp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST1</td>
<td>18.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.32</td>
<td>9.29</td>
<td>5.02</td>
<td>88.3</td>
<td>1.21</td>
<td>155</td>
</tr>
<tr>
<td>ST2</td>
<td>18.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.23</td>
<td>8.63</td>
<td>4.50</td>
<td>80.5</td>
<td>1.36</td>
<td>142</td>
</tr>
<tr>
<td>FF1</td>
<td>17.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.22</td>
<td>8.57</td>
<td>4.38</td>
<td>80.5</td>
<td>1.40</td>
<td>152</td>
</tr>
<tr>
<td>FF2</td>
<td>17.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.30</td>
<td>7.92</td>
<td>4.66</td>
<td>80.0</td>
<td>1.30</td>
<td>147</td>
</tr>
</tbody>
</table>
### GROW-OUT

**Summary of results 2006-2013**

*L. vannamei 2009 (108 d, 40 m³ Raceways, 0.99 g 450 juv/m³)*

<table>
<thead>
<tr>
<th>ID</th>
<th>Yield (kg/m³)</th>
<th>Av. Wt. (g)</th>
<th>Sur. (%)</th>
<th>FCR (g/wk)</th>
<th>Freshwater (%/day)</th>
<th>L/kg Shrimp</th>
<th>O₂: last 7 d (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST1</td>
<td>9.34</td>
<td>21.96</td>
<td>94.5</td>
<td>1.60</td>
<td>0.28</td>
<td>126</td>
<td>0.19</td>
</tr>
<tr>
<td>ST2</td>
<td>9.52</td>
<td>21.81</td>
<td>94.5</td>
<td>1.57</td>
<td>0.27</td>
<td>107</td>
<td>0.16</td>
</tr>
<tr>
<td>FF1</td>
<td>9.51</td>
<td>22.51</td>
<td>96.9</td>
<td>1.53</td>
<td>0.24</td>
<td>108</td>
<td>0.36</td>
</tr>
<tr>
<td>FF2</td>
<td>9.75</td>
<td>22.40</td>
<td>96.3</td>
<td>1.57</td>
<td>0.22</td>
<td>98</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**L. vannamei 2011, 40 m³ raceways**

<table>
<thead>
<tr>
<th>RW</th>
<th>Stocking (g)</th>
<th>Harvest (g)</th>
<th>Days</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR</th>
<th>Water Use L/1 kg</th>
<th>Sal (ppt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.9</td>
<td>22.16</td>
<td>81</td>
<td>1.75</td>
<td>87.6</td>
<td>9.66</td>
<td>1.39</td>
<td>169.0</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>23.63</td>
<td>82</td>
<td>1.86</td>
<td>81.5</td>
<td>9.59</td>
<td>1.44</td>
<td>160.8</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>1.9</td>
<td>23.36</td>
<td>82</td>
<td>1.83</td>
<td>80.7</td>
<td>9.40</td>
<td>1.45</td>
<td>149.0</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>1.9</td>
<td>23.79</td>
<td>83</td>
<td>1.85</td>
<td>79.3</td>
<td>9.39</td>
<td>1.45</td>
<td>161.0</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
<td>25.12</td>
<td>85</td>
<td>1.95</td>
<td>78.9</td>
<td>9.87</td>
<td>1.44</td>
<td>148.2</td>
<td>30</td>
</tr>
<tr>
<td>Av.</td>
<td>23.61</td>
<td>1.85</td>
<td>81.6</td>
<td>9.58</td>
<td>1.43</td>
<td>157.6</td>
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<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.94</td>
<td>0.06</td>
<td>0.3</td>
<td>0.18</td>
<td>0.02</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## GROW-OUT

### Summary of results 2006-2013

**L. vannamei 2010 (87 d, 100 m³ Raceways, testing a³)**

<table>
<thead>
<tr>
<th>RW</th>
<th>Yield (kg/m³)</th>
<th>Av. Wt. (g)</th>
<th>Survival (%)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.25</td>
<td>25.68</td>
<td>89.5</td>
<td>2.56</td>
<td>1.38</td>
</tr>
<tr>
<td>2</td>
<td>6.56</td>
<td>26.58</td>
<td>90.8</td>
<td>2.36</td>
<td>1.45</td>
</tr>
</tbody>
</table>

### L. vannamei 2011 (106 d, 100 m³ Raceways, Taura resistant line)

<table>
<thead>
<tr>
<th>RW</th>
<th>Stocking (Juv/m³)</th>
<th>Harvest (g)</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>390</td>
<td>3.14</td>
<td>25.14</td>
<td>1.45</td>
<td>79.7</td>
<td>1.83</td>
<td>166.6</td>
</tr>
<tr>
<td>2</td>
<td>390</td>
<td>3.14</td>
<td>25.39</td>
<td>1.47</td>
<td>86.3</td>
<td>1.70</td>
<td>149.7</td>
</tr>
</tbody>
</table>

**Av.**

<table>
<thead>
<tr>
<th>Stocking (Juv/m³)</th>
<th>Harvest (g)</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>390</td>
<td>3.14</td>
<td>25.26</td>
<td>1.46</td>
<td>83.0</td>
<td>8.36</td>
<td>158.1</td>
</tr>
</tbody>
</table>

**SD**

<table>
<thead>
<tr>
<th>Stocking (Juv/m³)</th>
<th>Harvest (g)</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>0.01</td>
<td>3.3</td>
<td>0.32</td>
<td>8.5</td>
<td>139.5</td>
<td>148.9</td>
</tr>
</tbody>
</table>

### L. vannamei 2012 (64 d, 100 m³ Raceways, special injector)

<table>
<thead>
<tr>
<th>RW</th>
<th>Stocking (Juv/m³)</th>
<th>Harvest (g)</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>3.6</td>
<td>22.76</td>
<td>2.13</td>
<td>80.2</td>
<td>1.43</td>
<td>139.5</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
<td>3.6</td>
<td>22.67</td>
<td>2.12</td>
<td>78.2</td>
<td>1.53</td>
<td>148.9</td>
</tr>
</tbody>
</table>

**Av.**

<table>
<thead>
<tr>
<th>Stocking (Juv/m³)</th>
<th>Harvest (g)</th>
<th>Growth (g/wk)</th>
<th>Survival (%)</th>
<th>Yield (kg/m³)</th>
<th>FCR (g/wk)</th>
<th>Water Use (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>3.6</td>
<td>22.72</td>
<td>2.12</td>
<td>79.5</td>
<td>9.03</td>
<td>144.2</td>
</tr>
</tbody>
</table>
## GROW-OUT
### Summary of results 2006-2013

#### L. vannamei 2012 (67 d, 40 m³ Raceways)

<table>
<thead>
<tr>
<th></th>
<th>HI-35 (g)</th>
<th>SI-35 (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Weight</td>
<td>22.12 ± 11.35a</td>
<td>19.74 ± 8.28b</td>
</tr>
<tr>
<td>Growth (g/wk)</td>
<td>2.03 ± 0.01a</td>
<td>1.76 ± 0.10b</td>
</tr>
<tr>
<td>Total Biomass</td>
<td>389.8 ± 1.77a</td>
<td>348.5 ± 9.21b</td>
</tr>
<tr>
<td>Yield (kg/m³)</td>
<td>9.74 ± 0.04a</td>
<td>8.71 ± 0.22b</td>
</tr>
<tr>
<td>FCR</td>
<td>1.25 ± 0.01a</td>
<td>1.43 ± 0.04b</td>
</tr>
<tr>
<td>Survival (%)</td>
<td>87.4 ± 0.52a</td>
<td>88.3 ± 4.18a</td>
</tr>
</tbody>
</table>

#### L. vannamei 2012 (63 d, 100 m³ Raceways)

<table>
<thead>
<tr>
<th>RW</th>
<th>Yield (kg/m³)</th>
<th>Av. Wt. (g)</th>
<th>Survival (%)</th>
<th>FCR</th>
<th>(g/wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.20</td>
<td>22.76</td>
<td>80.8</td>
<td>1.43</td>
<td>2.13</td>
</tr>
<tr>
<td>2</td>
<td>8.86</td>
<td>22.67</td>
<td>78.2</td>
<td>1.53</td>
<td>2.12</td>
</tr>
<tr>
<td>Average</td>
<td>9.03</td>
<td>22.72</td>
<td>79.5</td>
<td>1.48</td>
<td>2.13</td>
</tr>
</tbody>
</table>
GROW-OUT
Summary of results 2006-2013

*L. vannamei* 2013 (77 d, 40 m³ Raceways; 4.7 g juv. 324/m³)

<table>
<thead>
<tr>
<th></th>
<th>HI-35</th>
<th>EXP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Weight (g)</td>
<td>27.2 ± 0.9</td>
<td>28.8 ± 1.8</td>
</tr>
<tr>
<td>Growth (g/wk)</td>
<td>2.05 ± 0.13</td>
<td>2.16 ± 0.31</td>
</tr>
<tr>
<td>Total Biomass (kg)</td>
<td>328.3 ± 12.4</td>
<td>311.8 ± 45.2</td>
</tr>
<tr>
<td>Yield (kg/m³)</td>
<td>8.2 ± 0.3</td>
<td>7.8 ± 1.1</td>
</tr>
<tr>
<td>FCR</td>
<td>1.59 ± 0.01</td>
<td>1.72 ± 0.08</td>
</tr>
<tr>
<td>Survival (%)</td>
<td>93.1 ± 3.1ᵃ</td>
<td>83.4 ± 2.7ᵇ</td>
</tr>
</tbody>
</table>

- A preliminary economic analysis indicates that the HI-35 & EXP feeds would both be commercially viable when shrimp are sold at $4.00/lb.
Operations
GROW-OUT
Summary of results 2006-2013

- Nozzles (newly patented injectors) in raceways provided adequate aeration & mixing throughout the water column; eliminating the need for an air blower, air diffusers, airlifts, & supplemental oxygen, thus reducing energy use

- The significantly higher survival of shrimp fed HI-35 than those fed an experimental diet (EXP, 40% protein) in zero-exchange raceways over 77 d is attributed to the presence of a probiotic, VPack™, in the HI-35 feed
Operations
POST-HARVEST
Water re-use issues

- **Water storage**
  - Preliminary observations suggest no accumulation of heavy metals in the culture media over time
  - Preliminary observations suggest increase in K concentration in the culture media over time
  - The concentration of some elements in the culture media decreased significantly over time

- **Possible heavy metal accumulation**
  - Preliminary observations suggest differences between feeds which also affect the shrimp tissue content
  - Preliminary observations suggest no accumulation of heavy metals in the culture media over time
Operations
POST-HARVEST
Dealing with bacteria laden sludge

- Amounts & disposal requirements – new tools are being evaluated
- Government regulations
Acknowledgements

- National Sea Grant College Program for funding
- Florida Organic Aquaculture for the cooperation and the commercialization
- Texas A&M AgriLife Research for providing the support for the last 26 years
- Current and former researchers, students and staff members of the Texas A&M AgriLife Research Mariculture Lab for the hard work and dedication

A copy of the slide presentation of this workshop will be available at the: www.texasaquaculture.org