Perspectives on intensive, marine shrimp production using minimal-exchange indoor systems

- Opportunity and state of industry
- Production planning
- Culture tank and RAS design
- Biofloc technology
- Clear-water technology

Pacific white shrimp (Penaeus vannamei)

Douglas H. Ernst, Ph.D.
CTO, Planet Shrimp Inc., Ontario, Canada

Indoor Shrimp Farming Workshop
Kentucky State University, Sept 14-15, 2018
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Per capita consumption @ 4.2 lbs/person/year (high 4.5) x 367 million people (US 330 M, CAN 37 M) = 1.5 billion lbs per year 

90% Imported 
80% Imported farmed

1.5 billion lbs per year x Premium shrimp market @ 5% (for example) = 75 million lbs per year 

Potential market demand

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U.S. Farmed Shrimp Production 1988 - 2018

Source: USMSFP & G. Treece

2010 to 2018:
~ 3.5-4.0 M lbs/yr
5 % indoor?

22% of peak production

Declining market price
Increasing prod. cost

Specific Pathogen Free Hatcheries & PL Supply
Taura Syndrome Virus (TSV)
Biosecurity
TSV Resistance

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We quit raising shrimp because we found it wasn’t profitable. It cost too much to raise the shrimp indoors, considering the quantity of production.

“We have fought and fought the survival rate in the shrimp business for two and a half years and it has won every time.”

“At the end of the day, it was definitely devastating to see populations completely crash.”
## Shrimp Farm Design Procedure

<table>
<thead>
<tr>
<th>Design stage</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production plan</td>
<td>Target shrimp production (kg/week)</td>
</tr>
<tr>
<td>Production intensity</td>
<td>Target harvest density (kg/m3)</td>
</tr>
<tr>
<td></td>
<td>Stocking and harvest cycles, culture periods</td>
</tr>
<tr>
<td></td>
<td>Production staging: PL nursery --&gt; Growout</td>
</tr>
<tr>
<td>Facility size</td>
<td>Culture volumes for biomass &amp; density levels</td>
</tr>
<tr>
<td>Water reuse intensity</td>
<td>System water exchange (%/day)</td>
</tr>
<tr>
<td>RAS design</td>
<td>System type &amp; required water treatment</td>
</tr>
<tr>
<td></td>
<td>Biofloc, hybrid, and clear water RAS</td>
</tr>
<tr>
<td>Infrastructure design</td>
<td>Infrastructure, buildings, utilities, personnel</td>
</tr>
<tr>
<td>Enterprise budgets</td>
<td>Net costs &amp; revenues</td>
</tr>
</tbody>
</table>
Shrimp production plan:  
For facility design and production management

Shrimp survival, growth, and feeding

<table>
<thead>
<tr>
<th>Date</th>
<th>Shrimp age (day)</th>
<th>Mean weight (g)</th>
<th>Growth rate (g/wk)</th>
<th>Specific growth rate (%/d)</th>
<th>FCR (kg FD / kg BM)</th>
<th>Specific feeding rate (%bw/d)</th>
<th>Survival (%)</th>
<th>Shrimp pop. no.</th>
<th>Biomass (kg)</th>
<th>Feed app rate (kg/day)</th>
<th>Feed type</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Shrimp growth objectives (for example):

✓ Stock PL10 at 0.0025 g
✓ 1.0 g in 4 – 5 weeks
✓ 5.0 g in 7 weeks
✓ 1.5 – 2.5 g/wk to harvest (e.g. 30 g at 20 weeks at 2.0 g/wk)
Production plan: Shrimp growth from PL10 to harvest

Shrimp Growth: PLN, GO, and Maturation (PL10 to 45 g)

- **Exponential growth stanza**: PL10 - 5.0 g (0 - 7 weeks)
- **Linear growth stanza**: 5.0 - 35 g (8 - 22 weeks) GR = 2.0 g/wk
- **Asymptotic growth stanza**: 35 - 45+ g (22 - 40+ weeks)

Growth decline from initial linear rate indicates shrimp health issue.
Feed loading and metabolism: Oxygen consumption & Metabolite excretion

Stoichiometry of feed metabolism (example values)

<table>
<thead>
<tr>
<th>Metabolic ratios in relation to feed consumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen / feed (g O2 / g feed)</td>
<td>0.450</td>
</tr>
<tr>
<td>Carbon dioxide / feed (g CO2 / g feed)</td>
<td>0.500</td>
</tr>
<tr>
<td>Total ammonia nitrogen / feed (g N / g feed)</td>
<td>0.030</td>
</tr>
<tr>
<td>Phosphate / feed (g PO4-P / g feed)</td>
<td>0.005</td>
</tr>
<tr>
<td>Particulate solids / feed (g PS / g feed)</td>
<td>0.350</td>
</tr>
</tbody>
</table>

Metabolic ratios in relation to feed consumption:
- Oxygen (O2)
- Carbon dioxide (CO2)
- Total ammonia nitrogen (TAN)
- Ortho phosphate (PO4-P)
- Dry weight solids

Used for “mass balances” in water treatment design:
- Oxygen consumption and supply
- Carbon dioxide production and removal
- Ammonia production and nitrification → Nitrate denitrification
- Particulate solids production and removal
Feed loading and metabolism: Example application to Nitrogen cycle

Nitrifying bacteria production and inoculation (new PLN water)
- Shrimp population: 100,000
- Shrimp mean weight: 0.01 g
- Feeding rate: 40 % body wt./day
- Feed app rate: 400 g feed / day
- Ammonia loading rate: 12 g TAN/day
- Nitrifying bacteria production: 12 g TAN/day → 46 g/day for NH4Cl application

Nitrate denitrification reactor design
- Shrimp population: 100,000
- Shrimp mean weight: 30 g
- Feeding rate: 1.25 % body wt./day
- Feed app rate: 37.5 kg feed / day
- Nitrate loading rate: 1125 g NO3/day → DNR reactor design
System type: Biofloc & Clear-Water Technologies

Continuum of water quality management methods

Higher exch. recirculating biofloc
- Shrimp tank aeration
- Shrimp tank heating
- Biofloc cropping (clarifiers)

For example:
WER = 100 days

Lower exch. recirculating biofloc
- Plus:
  - Nitrate denitrification
  - Solids dewatering
  - Mineral balancing

For example:
WER = 300 days

Recirculating clear-water (no biofloc)
- Solids filtration, dewatering
- Biofiltration (MBBR)
- Foam fractionation
- CO2 stripping
- Oxygenation, ozonation
- UV disinfection
- Nitrate denitrification

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Biofloc technology: System design

- **TAN & NO2 oxidizing bacteria**
- **Probiotic bacteria**
- **Bacteria production**
- **Sludge digestion or utilization**
  - NO3 and PO4 removal
  - Potential mineral balancing

**Shrimp Culture Tanks**
- Shrimp & Biofloc
- Nutrient cycling microbes
- Water treatment bacteria

**Floc cropping & NO3 denit.**

**Sludge handling**
- Water reconditioning
Biofloc technology: Shrimp tank components

Circular tank or D-Ended raceway with central divider

Vapor-seal enclosure (isolate & ventilate tank air space)

Automated feeding

Automated monitoring & control
Water temp. & DO

Shrimp habitat (optional)

Water aeration
Vertical mixing
Horizontal circulation

Water treatment and reuse

Hydronic heating

Molt & mort collection sump

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Nozzle advantages:

- No maintenance
- Biofloc particle shear
- Horizontal water circulation
- Small bubble size → High surface area
- High air/water ratio → CO₂ degas
Biofloc Tech: Natural Shrimp (TX)

- Shrimp tank air enclosures
- Continuous biofloc cropping
- Continuous denitrification
- Automated M&C (YSI 5200)
  - 24/7 feed application
  - Water heating
  - Dissolved oxygen
Biofloc Tech: NaturalShrimp (TX)
Biofloc Tech: GambaNatural (Spain)

2012 (75,000 ft²)
Florida Organic Aquaculture

- **Building**: ¼ mile long, 182,000 ft², 4.5 million gal
- **D-ended raceways**: 300’ x 30’ x 5’ deep, central partition, sand bag walls, HDPE liner
Biofloc Tech: Ithuba Shrimp Farm (FL)

Ithuba Shrimp Farm (Fellsmere, Florida)
Les Knoesen (lesknoesen@gmail.com, +1-561-319-1817, ithubashrimp.com)

Barn: 160’x 90’ – 14 000 sq. ft.
D-ended raceways: 8 RWs, 64’x16’x4’ deep, 25,000 gal, central partition, wood and sand bag walls, HDPE liner
Production: 2500 lbs/months
Sludge removal:
- 0.25% – 0.50 %/day
- Start 60 days after stocking
- Water use ~ 300 days
1. Build farm, grow shrimp (2005 – 2007, NaturalShrimp, TX). Studied the literature, built a farm, commenced production at target harvest 10 kg/m3. Achieved good results.

2. Declining performance. At about 12 - 18 months of continuous production, started to see (1) declining shrimp growth and survival and (2) periodic, sudden, catastrophic mortality events (e.g. 10 %/day for 10 days)

4. **Confusion.** Primary stressors not found. Multiple shrimp biofloc presentations at aquaculture conferences, but nobody discussing Vibrio bacteria and related production issues.

5. **Enlightenment.** Published studies are non-continuous production. Therefore, effectively disinfecting between production runs. Lack of reporting for failed studies. Production issues by others in commercial industry also due to Vibrio bacteria?

6. **Conclusions.** High shrimp density by itself is a trigger for Vibrio virulence. Need to use lower shrimp densities. Or better shrimp genetics? Also use rotational disinfection of water and biofilms to control internal development of virulent Vibrio strains.
Vibrio: Ecology and Virulence

Vibrio ecology & virulence

• Non-excludable pathogen: Brought in with every PL reception
• Fast doubling time (30 min) \( \Rightarrow \) Population spikes
  \( \Rightarrow \) Evolution of virulence within facility
• Virulence triggers: High shrimp density (as well as poor WQ, stress, etc.)
• Quorum sensing: Latent \( \Rightarrow \) virulent switching for whole populations
• Virulence expression: Chitinase & protease excretion \( \Rightarrow \) Shrimp mortality
  Transmission via water & cannibalism of dead shrimp

Some pathogenic species: *V. parahaemolyticus, V. vulnificus, V. alginolyticus, Vibrio harveyi*

Vibrio colonies on TCBS agar
Vibrio electron micrograph
Biofloc Technology: Three Key Considerations

1. Effective aeration and water mixing
   - Adequate O2 supply and CO2 removal (> = 70 – 80 % DO sat.)

2. Nitrogen cycle
   - Control ammonia & nitrite w/ adequate nitrifying bacteria populations
   - Avoid use of carbon addition to control ammonia (by HB uptake)
     (occurs at C/N Ratio > 12 – 15, e.g. CNR for 35% protein feed = 8.9)
   - Control nitrate levels by water exchange, denitrification, or IMTA
     (e.g. < 50 mg N/L for 8 ppt salinity, < 100 mg N/L for 15 ppt salinity)
3. Proactive Vibrio control methods

- Max shrimp density ≤ 5 – 6 kg/m³ (anyone higher?)
- Probiotic bacteria apps for water and feed
- Shrimp feed immunostimulants
- Vibrio resistant shrimp genetics
- Rotational water and biofilm disinfection
- New/recond. biofloc water for new production lots
- Tank hygiene: Remove molts & morts
Control of Vibrio: Probiotic Bacteria

**Common probiotic species:**
- Bacillus spp.
- Lactobacillus spp.
- Pediococcus spp.
- Enterococcus spp.

**Action of probiotic bacteria**
- Competitive exclusion
- Anti-bacterial compounds
- Quorum sensing disruption

**Bacillus production in fermentation reactors**
- Brackish water, sugar, heaters, airlocks
- Add to shrimp culture water at high rates

**Bacillus plating**

**Bacillus bacteria**
Biofloc Systems: Application of “Symbiotics”

Symbiotics
• A relatively new management tool in global shrimp farming (Asia and Latin America)
• Used to stabilize water quality and ecology (desired algal species, beneficial bacteria, micro-organisms)
• Used to control Vibriosis and other diseases

From: David Kawahigashi, 2018
Vannamei 101, Thailand
Biofloc technology: Symbiotics Prep

Preparation of activated carbohydrate-probiotic solution
Apply to shrimp production, maturation, and larval rearing

(Example dry weight dosage: 5.0 ppm = 5.0 g per m3 = 100 mL per m3)

Fermented Rice Bran Formula

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice bran (12-20% fat or lipids)</td>
<td>1 kilogram</td>
</tr>
<tr>
<td>Seawater (sterilized)</td>
<td>10–20 liters</td>
</tr>
<tr>
<td>Enzyme / probiotic</td>
<td>5-10 grams or ml</td>
</tr>
<tr>
<td>Buffer – Na2(HO3) or CaC03</td>
<td>5% or 50 grams per kilo RB</td>
</tr>
<tr>
<td>Aeration</td>
<td>Moderate to strong</td>
</tr>
</tbody>
</table>

From: David Kawahigashi, 2018
Vannamei 101, Thailand
Biofloc Technology: Application of Symbiotics

Countries using symbiotics:

Worldwide, see variable use of:

- Aerobic or fermentative production of particulate carbon + probiotic solution
- Carbon sources: Rice bran, soy, sweet potato, cassava, etc.

<table>
<thead>
<tr>
<th>Countries using symbiotics</th>
<th>Level of use (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>60%</td>
</tr>
<tr>
<td>Ecuador</td>
<td>20%</td>
</tr>
<tr>
<td>Belize</td>
<td>100%</td>
</tr>
<tr>
<td>Mexico</td>
<td>30%</td>
</tr>
<tr>
<td>Korea (indoor farms)</td>
<td>70%</td>
</tr>
<tr>
<td>Thailand</td>
<td>20%</td>
</tr>
<tr>
<td>Vietnam</td>
<td>5%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5%</td>
</tr>
<tr>
<td>Philippines</td>
<td>1%</td>
</tr>
<tr>
<td>China</td>
<td>1%</td>
</tr>
<tr>
<td>India</td>
<td>70%</td>
</tr>
<tr>
<td>Malaysia</td>
<td>5%</td>
</tr>
</tbody>
</table>

From: David Kawahigashi, 2018
Vannamei 101, Thailand
Symbiotic BFT
Sinaloa, México
June 2018

Harvest density
4 kg / m²

From: David Kawahigashi, 2018
Vannamei 101, Thailand

- 2,000 m² x 1.2 m x 8 raceways
- Densidad de siembra: 250 PL12/m²
- Sinbiótica: arroz fermentado
- 4 kilos por m² cosecha (antes 1-2 kg/m²)
- Tamaño: 16-18 gramos en 85 DOC
- 85% supervivencia promedio

<table>
<thead>
<tr>
<th>Crecimiento</th>
<th>KonaBaySPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOCengorda</td>
<td>63días</td>
</tr>
<tr>
<td>Densidadsiembra</td>
<td>150PL12(.2gr)</td>
</tr>
<tr>
<td>Árearaceway</td>
<td>2,000m2(lined)</td>
</tr>
<tr>
<td>Tamaño</td>
<td>22gramos</td>
</tr>
<tr>
<td>ADGengorda</td>
<td>.34</td>
</tr>
</tbody>
</table>
### Symbiotic Biofloc Technology: South Korea

<table>
<thead>
<tr>
<th>IndoorRaceway</th>
<th>AntesFRB</th>
<th>DespuésFRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervivencia</td>
<td>45%</td>
<td>71%</td>
</tr>
<tr>
<td>Densidadsiembra</td>
<td>220/m²</td>
<td>300/m²</td>
</tr>
<tr>
<td>Pesocosecha</td>
<td>19gramos</td>
<td>20gramos</td>
</tr>
<tr>
<td>Kilos/m²</td>
<td>1.8kilos</td>
<td>4.2kilos</td>
</tr>
<tr>
<td>Biomasatotal</td>
<td>3,300kilos</td>
<td>7,600kg</td>
</tr>
<tr>
<td>Díasdecultivo</td>
<td>167días</td>
<td>118días</td>
</tr>
<tr>
<td>FCR</td>
<td>1.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Isla Ganghwa**

**Isla Jeju**

- Lenguado a vannamei
- Camarón vivo => $30-40/kilo
- 2 ciclos al año; pre-cría 30 doc
- 600 m² raceways x 3 por granja
- 4-6 kilos/m² por ciclo
- Casi cero recambio / simbióticas

From: David Kawahigashi, 2018
Vannamei 101, Thailand
Back to my experience:
Is clear-water shrimp culture a viable option?

**Biofloc Advantages**
- Relatively simple operation
- Relatively low facility construction and operation costs

**Biofloc Disadvantages**
- Max commercial shrimp density: 5 – 6 kg/m³ (?)
- Disinfect harmful bacteria → Impact beneficial bacteria
Shrimp Production in Clear Water

Clear-Water Advantages
- Can see shrimp crops, better population tracking
- Continuous water disinfection and suppression of Vibrio
- Higher commercial production densities

Clear-Water Disadvantages
- Higher facility construction costs
- Increased system operation and management complexity
My first study: Shrimp production in clear water

A break from conventional wisdom: Convert biofloc to clear-water

NaturalShrimp (TX)
Shrimp Production in Clear Water

Clear-Water System Results

- Higher sustainable shrimp densities
- More consistent production
- Improved growth, survival, FCR

Natural Shrimp
La Coste, TX
2011
Shrimp Production in Clear Water

Natural Shrimp, La Coste, TX (2012)
Planet Shrimp: Clear-Water Technology

Planet Shrimp
Aylmer, Ontario
Planet Shrimp: Clear-Water Technology

Repurposed warehouses: Four buildings at 65,000 ft² each
Planet Shrimp: Clear-Water Technology

Minimal-Exchange Recirculating Aquaculture Systems

Shrimp culture tanks
- Stacked shallow raceways
- Multi-stage growout

Water treatment processes
- Solids filtration
- Biofiltration
- CO2 degassing
- Foam fractionation
- Oxygenation
- Ozonation
- UV disinfection
- Sludge dewatering
- Denitrification

Water treatment and recirc
Planet Shrimp: Clear-Water Technology

Stacked Raceway Shrimp Culture Units
Planet Shrimp: Clear-Water Technology

Shrimp Tank Access Corridors
Planet Shrimp: Clear-Water Technology

Shrimp Harvesting Started June 2018