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

U.S. & Canada Shrimp Market

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

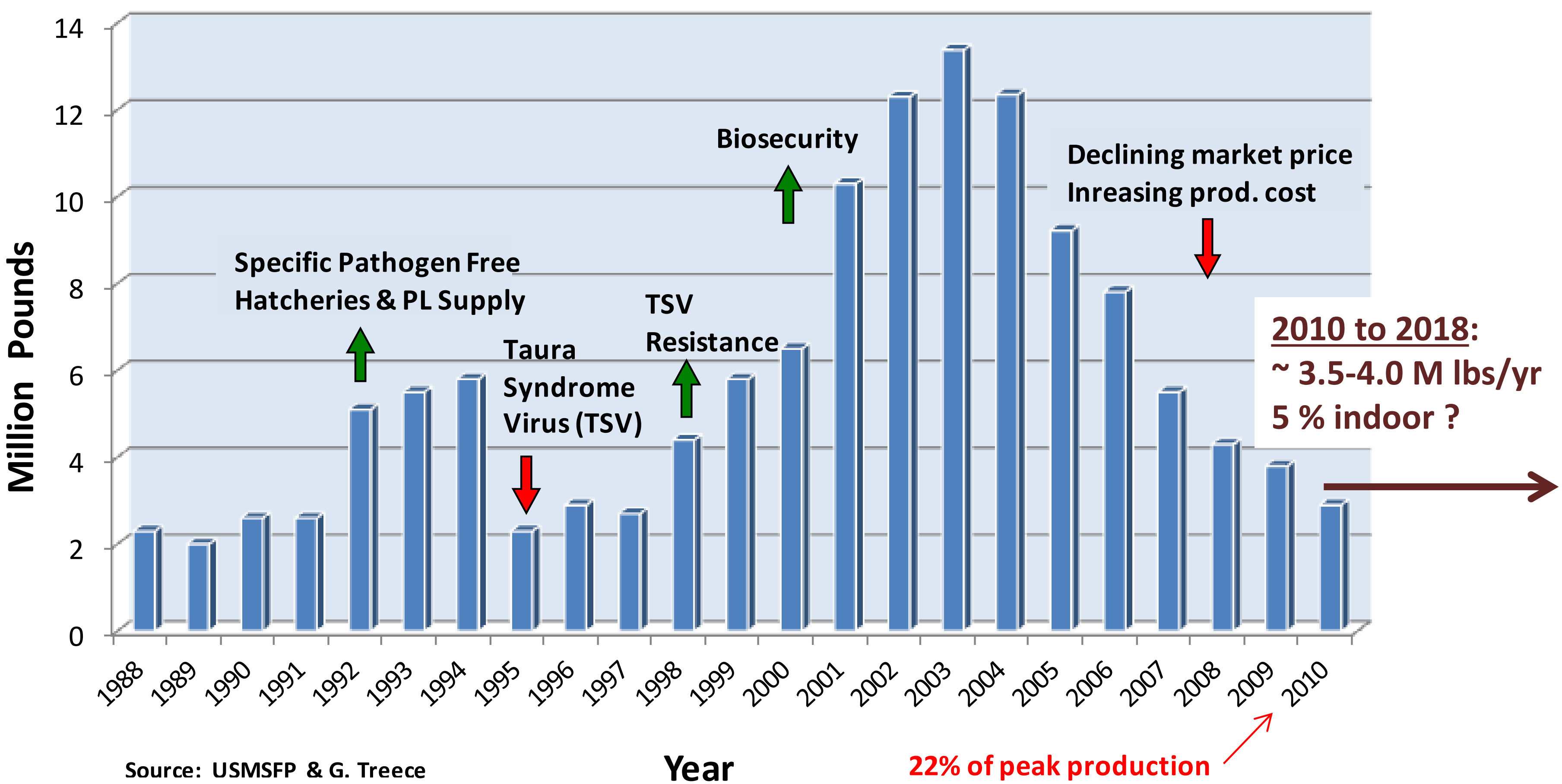
90% Imported
80% Imported farmed

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

= 75 million lbs per year

Potential market demand

U.S. Farmed Shrimp Production 1988 - 2018



Source: USMSFP & G. Treece

Status of indoor shrimp production industry in U.S. and Canada

A history of failures for small and large indoor shrimp facilities …

CAUTION !

<u>**The indoor farmed shrimp business: fascinating, frustrating**</u>

Global Aquaculture Advocate, November 2016

www.aquaculturealliance.org/advocate/the-indoor-farmed-shrimp-business-fascinating-frustrating/

"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

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

Shrimp production plan:
For facility design and production management

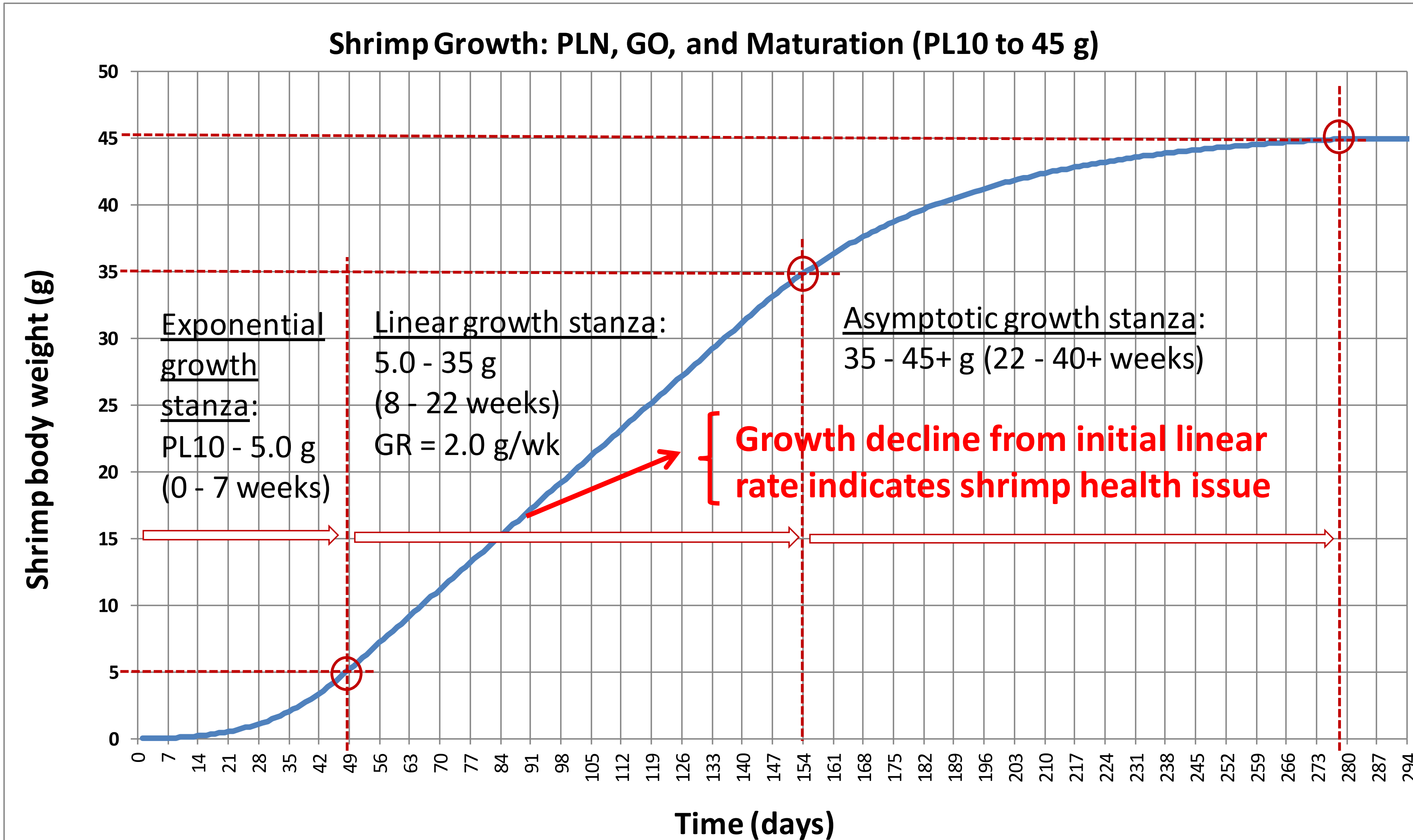
Shrimp survival, growth, and feeding

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

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



Feed loading and metabolism: Oxygen consumption & Metabolite excretion

Stoichiometry of feed metabolism (example values)

Metabolic ratios in relation to feed consumption		
Oxygen / feed (g O_2 / g feed)	0.450	*O_2*
Carbon dioxide / feed (g CO_2 / g feed)	0.500	*CO_2 (RQ x 1 mol CO_2 per mol O_2)*
Total ammonia nitrogen / feed (g N / g feed)	0.030	*Total ammonia nitrogen (TAN)*
Phosphate / feed (g PO_4-P / g feed)	0.005	*Ortho phosphate (PO_4-P)*
Particulate solids / feed (g PS / g feed)	0.350	*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 NH_4Cl 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 NO_3/day → DNR reactor design

System type: Biofloc & Clear-Water Technologies

Continuum of water quality management methods

Higher exch. recirculating biofloc	Lower exch. recirculating biofloc	Recirculating clear-water (no biofloc)

Higher exch. recirculating biofloc

- Shrimp tank aeration
- Shrimp tank heating
- Biofloc cropping (clarifiers)

For example:
WER = 100 days

Lower exch. recirculating biofloc

Plus:

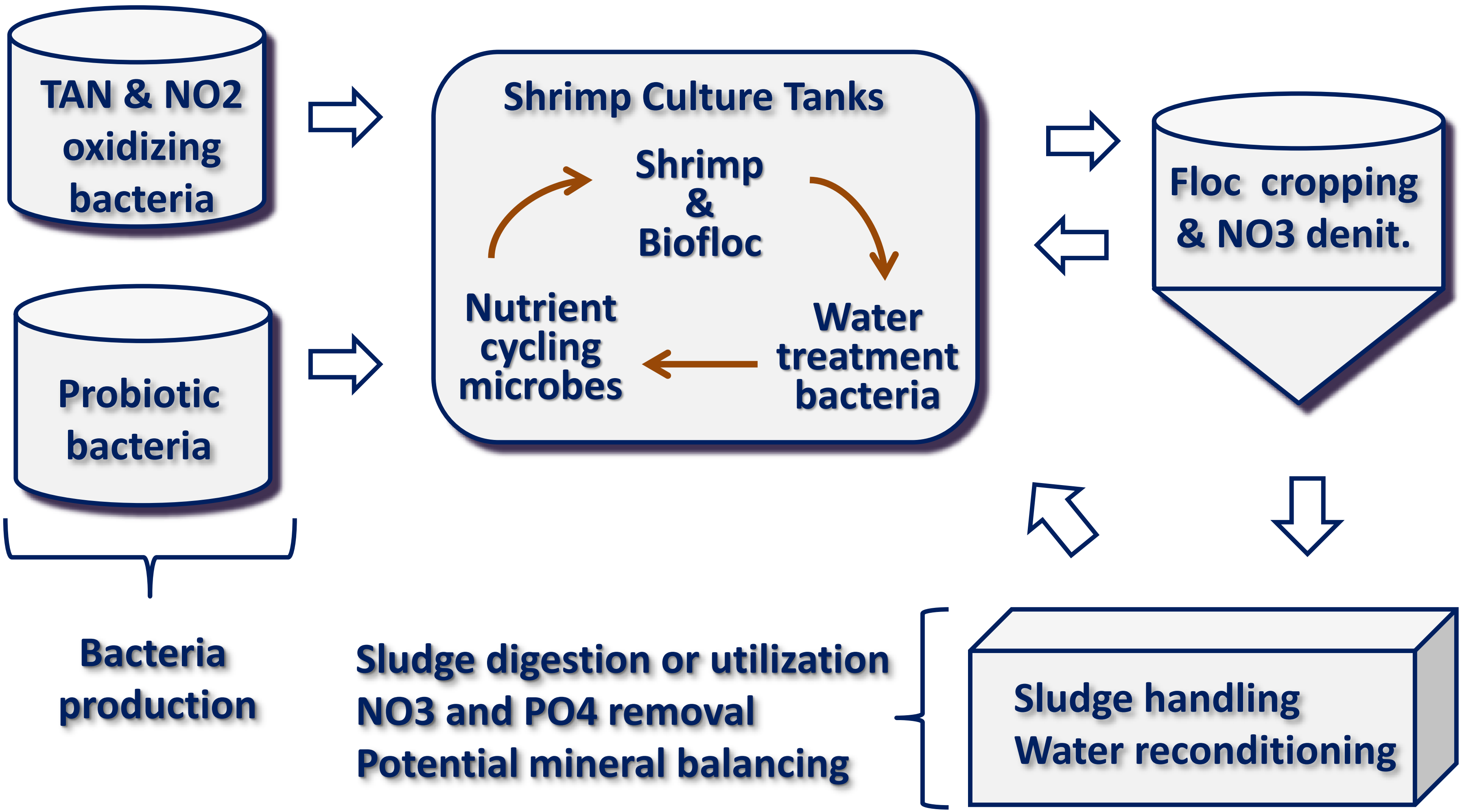
- Nitrate denitrification
- Solids dewatering
- Mineral balancing

For example:
WER = 300 days

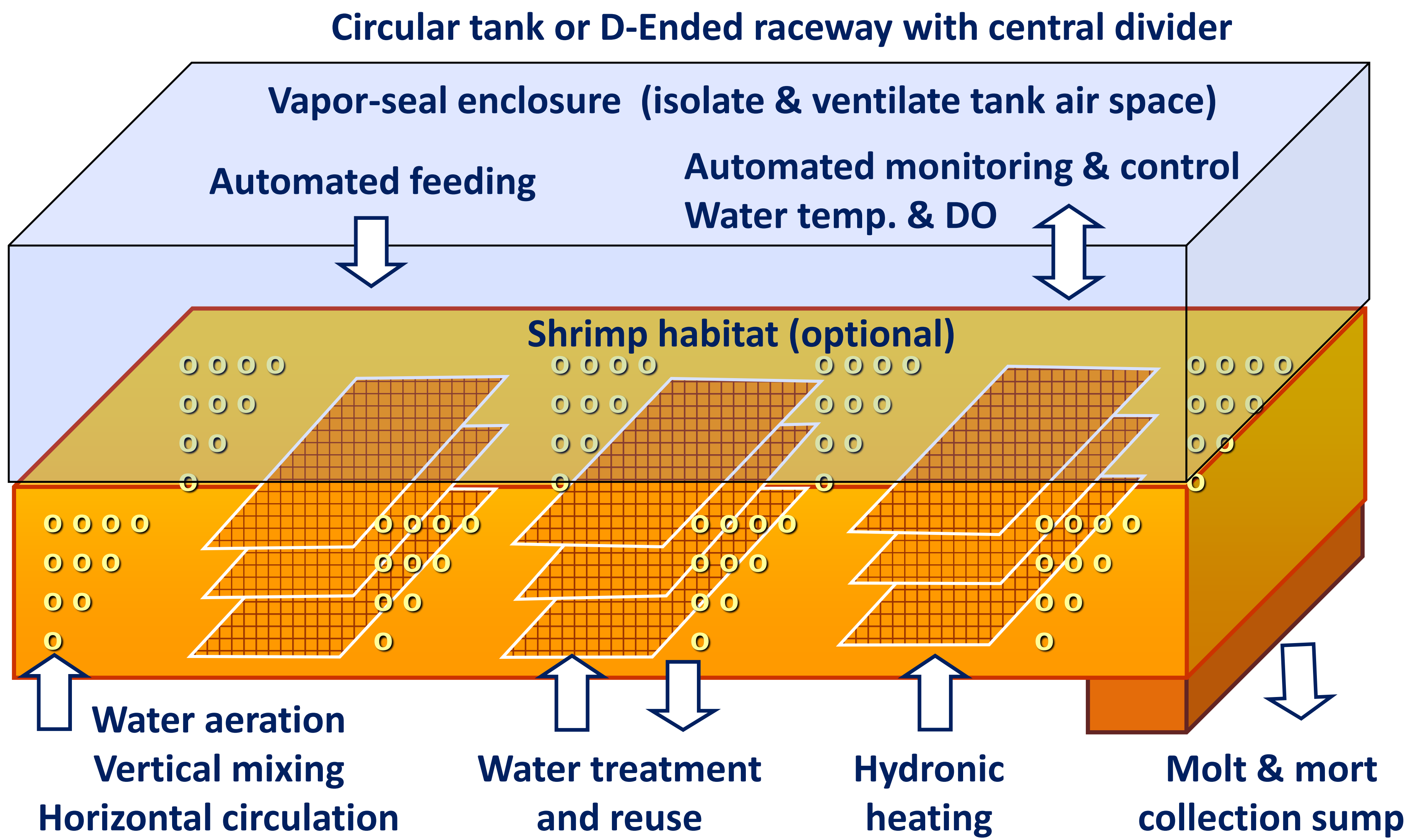
Recirculating clear-water (no biofloc)

- Solids filtration, dewatering
- Biofiltration (MBBR)
- Foam fractionation
- CO_2 stripping
- Oxygenation, ozonation
- UV disinfection
- Nitrate denitrification

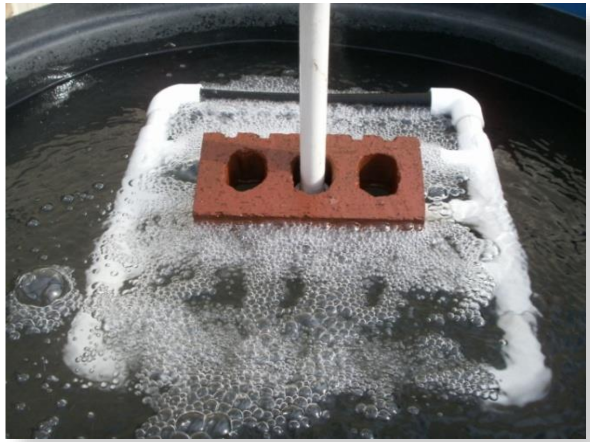
Biofloc technology: System design



Biofloc technology: Shrimp tank components



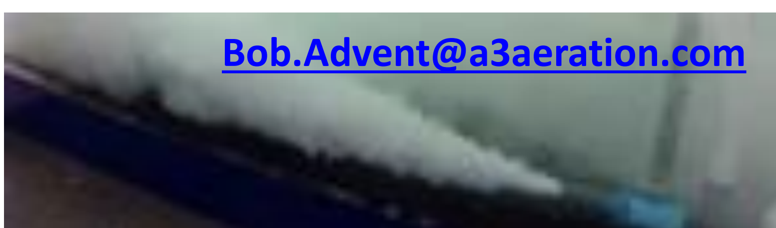
Biofloc Aeration: Diffusers vs. Nozzles



Nozzle advantages:

- No maintenance
- Biofloc particle shear
- Horizontal water circulation
- Small bubble size → High surface area
- High air/water ratio → CO_2 degas

Bob.Advent@a3aeration.com



Bob.Advent@a3aeration.com

Biofloc Tech: NaturalShrimp (TX)

Biofloc Tech: NaturalShrimp (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)

Biofloc Tech: Florida Organic Aquaculture

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

From Les Knoesen, Ithuba Shrimp Farm

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

From Les Knoesen, Ithuba Shrimp Farm

Biofloc Tech: Ithuba Shrimp Farm (FL)

Sludge removal:

- 0.25% – 0.50 %/day
- Start 60 days after stocking
- Water use ~ 300 days

From Les Knoesen, Ithuba Shrimp Farm

Back to My Experience: Biofloc + Shrimp = Vibrio

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)**

3. **Seeking causes and solutions. Completed histopathology and PCR. Tissue damage consistent with Vibriosis. *Vibrio parahaemolyticus* isolated and identified. Vibrio considered to be an opportunistic pathogen. Look for primary stressor.**

My Experience: Biofloc + Shrimp = Vibrio

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

5. <u>Enlightenment</u>. 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. <u>Conclusions</u>. 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.

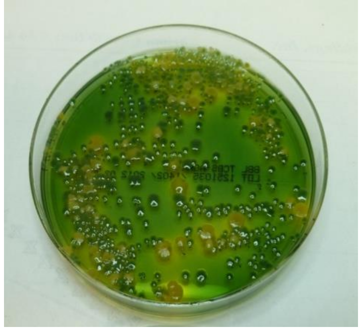
Vibrio: Ecology and Virulence

Vibrio ecology & virulence

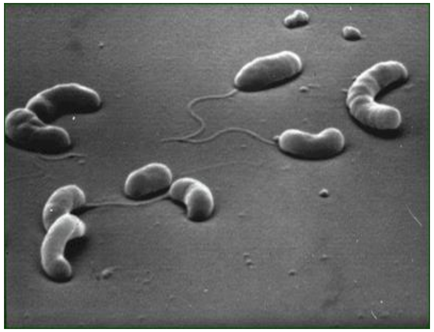
- **Non-excludable pathogen: Brought in with every PL reception**
- **Fast doubling time (30 min) → Population spikes**
  → Evolution of virulence within facility
- **Virulence triggers: High shrimp density (as well as poor WQ, stress, etc.)**
- **Quorum sensing: Latent → virulent switching for whole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

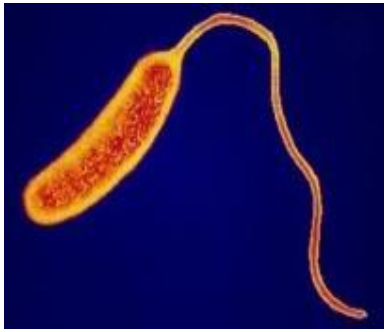
Some pathogenic species: *V. parahaemolyticus, V. vulnificus, V. alginolyticus, Vibrio harveyi*

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. $\leq$ 50 mg N/L for 8 ppt salinity, $\leq$ 100 mg N/L for 15 ppt salinity)

Biofloc Technology: Three Key Considerations

3. Proactive Vibrio control methods

- Max shrimp density $\leq$ 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

Action of probiotic bacteria

- Competitive exclusion
- Anti-bacterial compounds
- Quorum sensing disruption

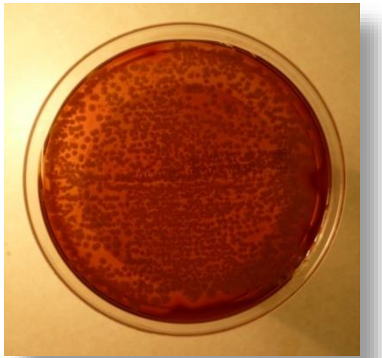
Common probiotic species:

- *Bacillus spp.*
- *Lactobacillus spp.*
- *Pedioccous spp.*
- *Enterococcus spp.*

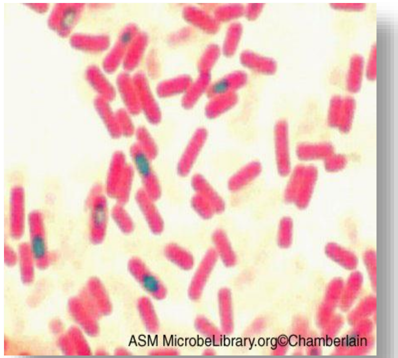
Bacillus production in fermentation reactors

- Brackish water, sugar, heaters, airlocks
- Add to shrimp culture water at high rates

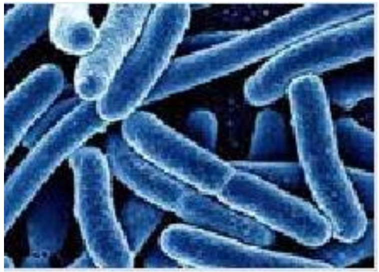
Bacillus plating

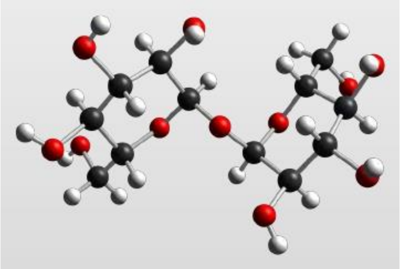


Bacillus bacteria



Biofloc Systems: Application of “Symbiotics”





Probiotics + Carbohydrates + Fermentation → Symbiotics

Symbiotics

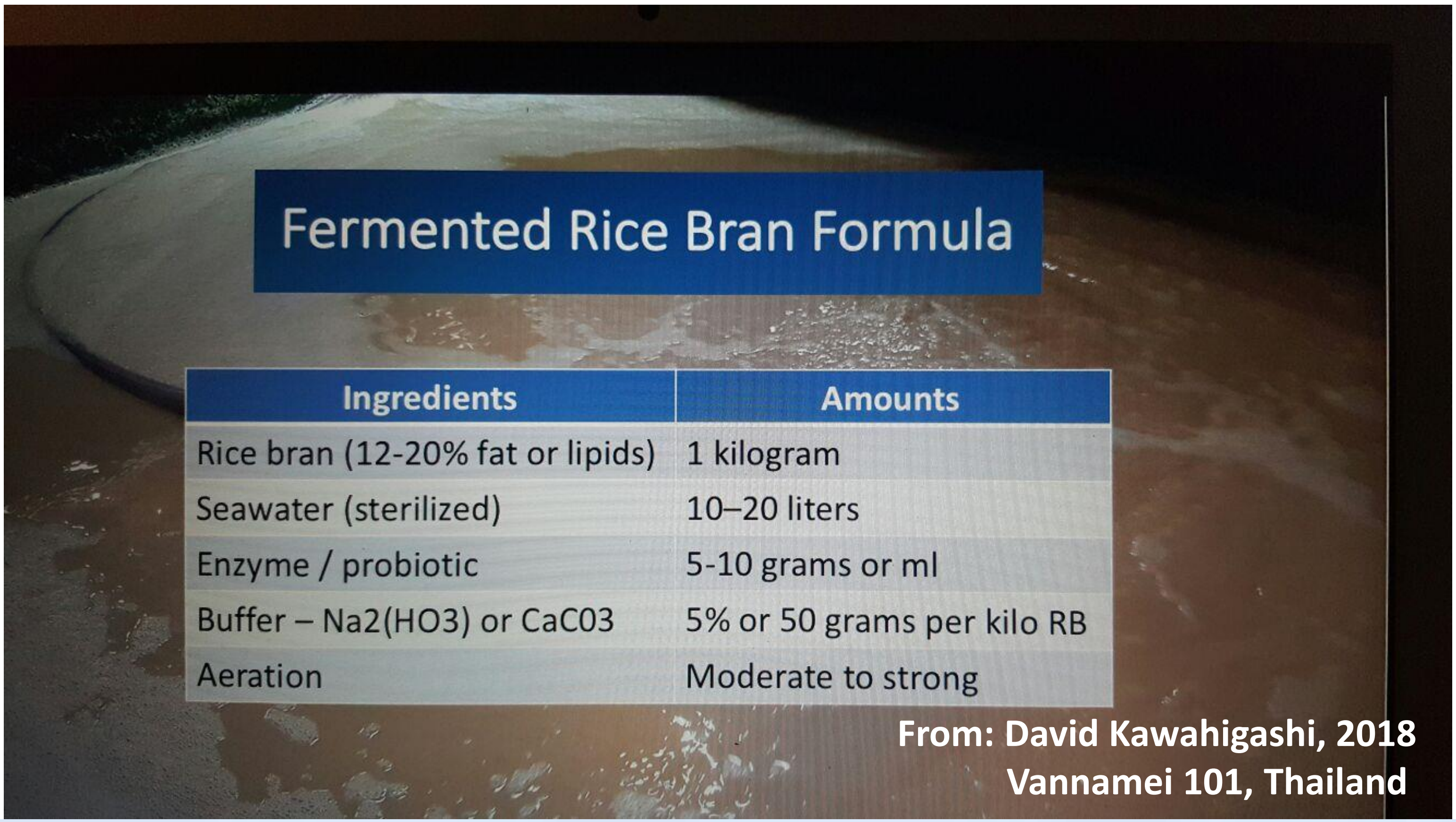
- **A relatively new management tool in global shrimp farming (Asia and Latin America)**
- **Used to stabilize water quality and ecology (desired algal species, beneficial bacteria, micro-organisms)**
- **Used to control Vibriosis and other diseases**

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

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

From: David Kawahigashi, 2018
Vannamei 101, Thailand

Biofloc Technology: Application of Symbiotics

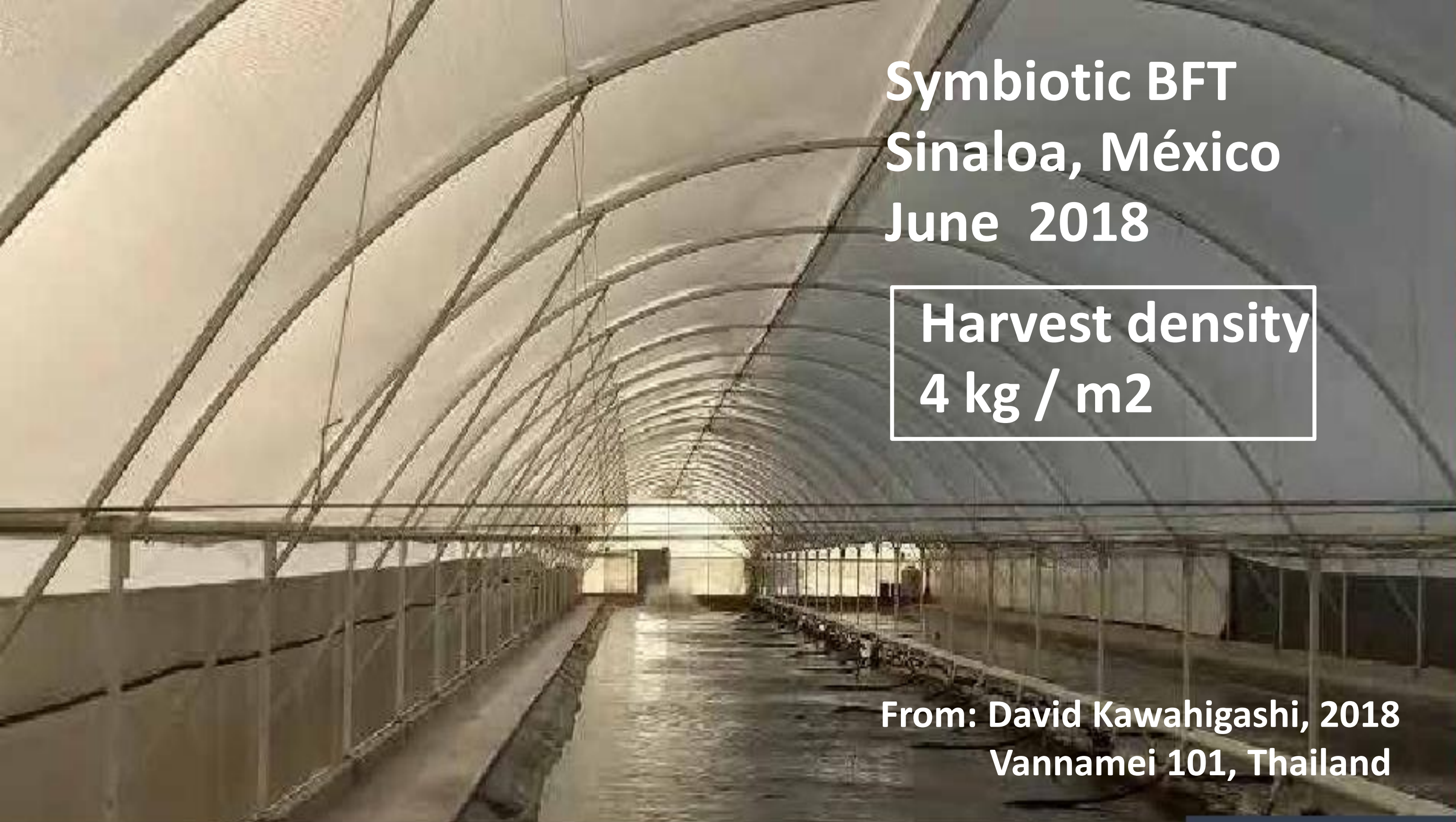
Countries using symbiotics:

Worldwide, see variable use of:

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

Countries using symbiotics	Level of use (%)
Brazil	**60%**
Ecuador	20%
Belize	**100%**
Mexico	30%
Korea (indoor farms)	**70%**
Thailand	20%
Vietnam	5%
Indonesia	5%
Philippines	1%
China	1%
India	**70%**
Malaysia	5%

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

Crecimiento	KonaBaySPF
DOCengorda	63días
Densidadsiembra	150PL12(.2gr)
Árearaceway	2,000m2(lined)
Tamaño	22gramos
ADGengorda	.34

Symbiotic Biofloc Technology: South Korea

IndoorRaceway	AntesFRB	DespuésFRB
Supervivencia	45%	71%
Densidadsiembra	220/m2	300/m2
Pesocosecha	19gramos	20gramos
Kilos/m2	**1.8kilos**	**4.2kilos**
Biomasatotal	3,300kilos	7,600kg
Díasdecultivo	167días	118días
FCR	1.6	1.4

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

Isla Ganghwa

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

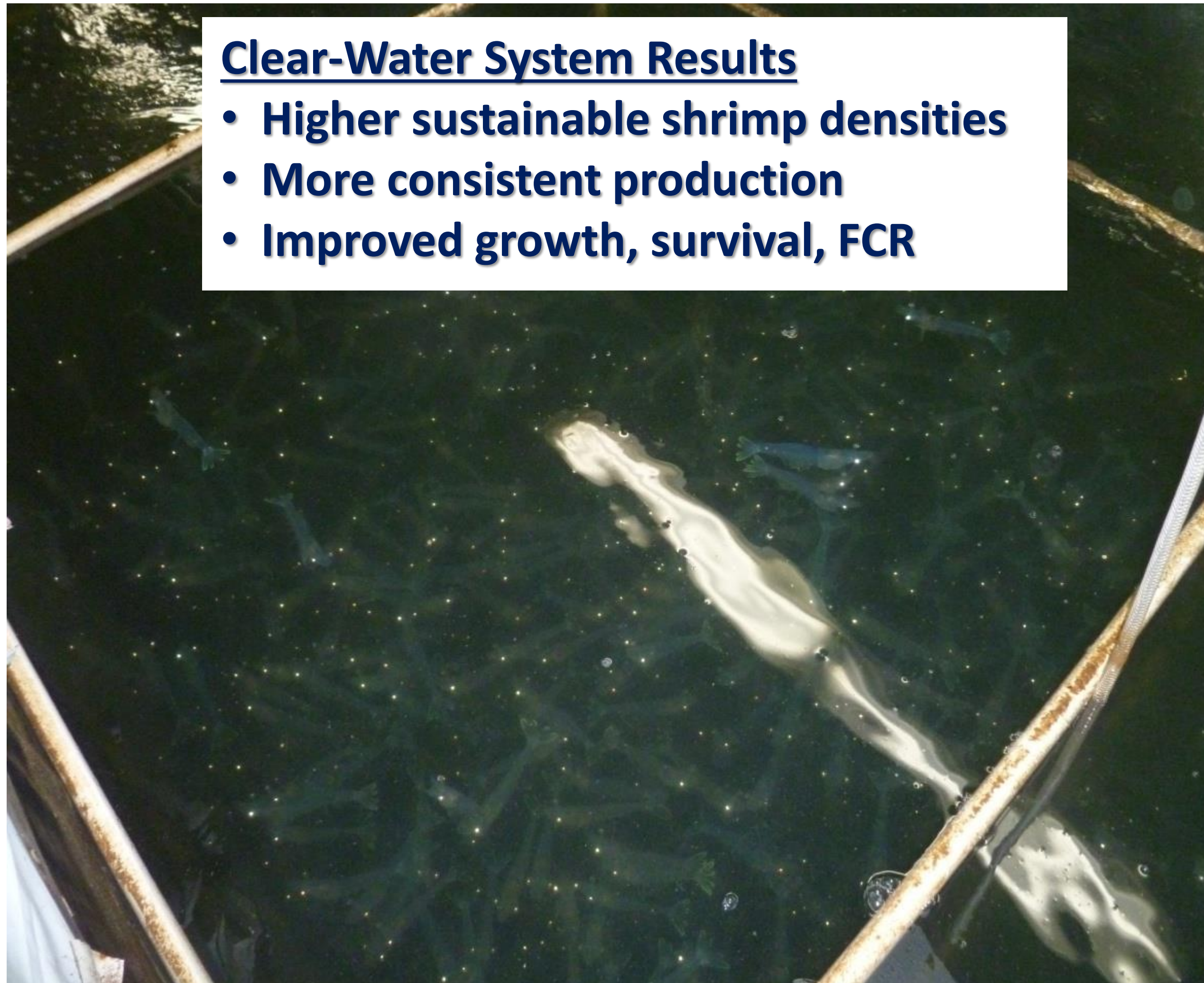
Clear-Water Disadvantages

- 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

Shrimp Production in Clear Water

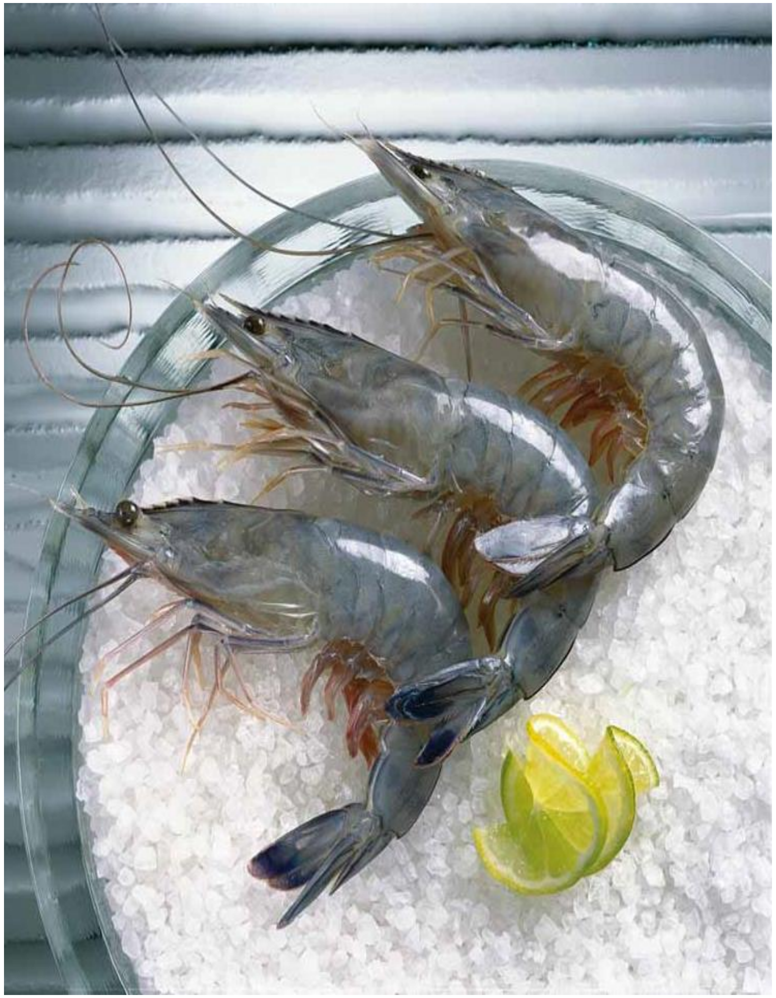


<u>Clear-Water System Results</u>

- **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

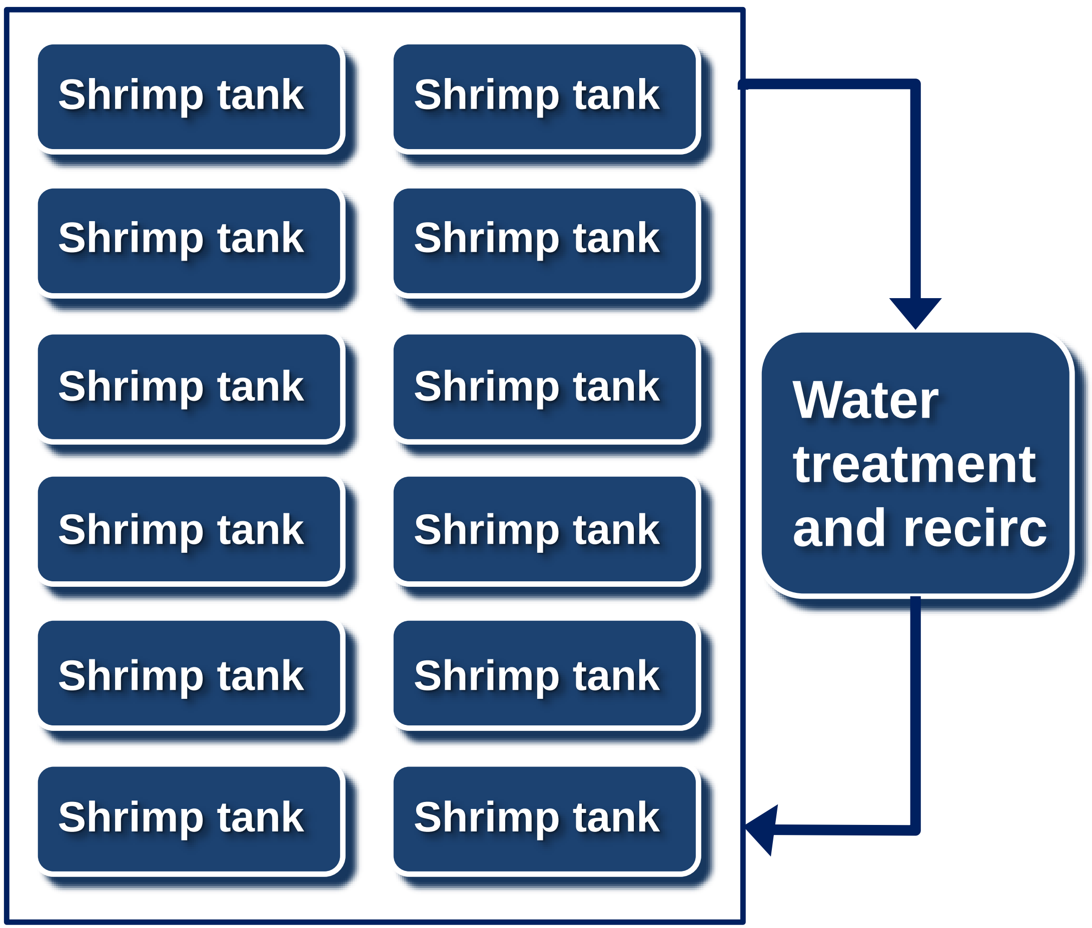
PLANET
SHRIMP
AYLMER, CANADA

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

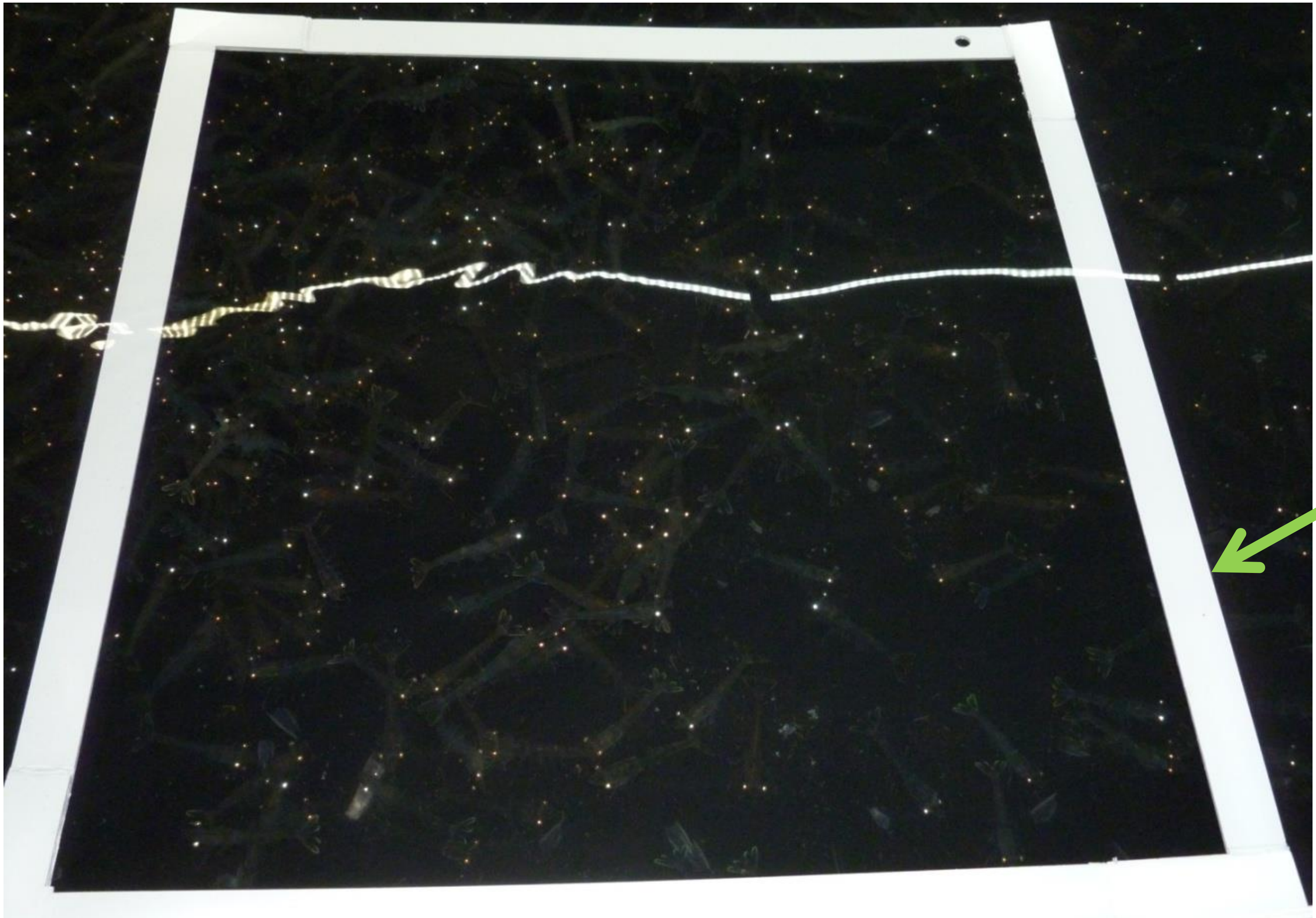
Planet Shrimp: Clear-Water Technology

Stacked Raceway Shrimp Culture Units

Planet Shrimp: Clear-Water Technology

Shrimp Tank Access Corridors

Planet Shrimp: Clear-Water Technology



Shrimp in Shallow Raceways

1.0 m2 floating frame

Planet Shrimp: Clear-Water Technology

Shrimp Harvesting Started June 2018