Autotrophic and Heterotrophic Water Treatment in Intensive and Semi-Intensive Aquaculture

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Overview of Aquaculture; Name, Yield, Feed, Aeration, Solids, Microbial Type, Solids, Inception Date

SYSTEM	Yield lb/ac	Feed lb/ac-d	Aeration hp/ac	Type g-C/m^2-d	VSS mg/l	Timeline
Extensive	1,000-2,000	10-30	Wind	Pond Algal (0.5-1)	10-20	1960
Semi- Intensive	4,000-6,000	50-100	1-2	Pond Algal (2-3)	50-100	1980
Intensive pond	10,000-12,000	100-150	6-20	Mixed (3-4)	100+	1990
PAS/SP	15,000-19,000	200-250	7-10	Enhanced Algal (6-12)	50-100	2000
Super nitrifying	40,000+	1,000	50-60	Nitrification (12-30)	300-400	2006
Super heterotrophic	40,000+	1,000/600	60-80	Heterotrophic (20-50)	300-400	2006
Rapid Removal	30,000-44,639	1,500	67-76	Intense Nitrification	70-80	2020

Over 60 years, from “wild” pond photosynthesis, to enhanced algal, to enhanced nitrification/heterotrophic microbal management of ammonia with increasing aeration energy

Physical Configuration, Stocking, Projected Yields

Ponds, Tanks, Raceway/Hybrid Ponds

Wind-Aerated Stillwater Pond Production

1) Transfer rate: KLA (hr^{-1}) = 0.017 (Wind m/s) – 0.014
2) Oxygen available: mg-O_2/l-d = KLA (Cs-C)
3) Wind = 5 m/s, delta O_2 = 5 mg/l, O_2 transfer = 45 lb/ac-d
4) Fish O_2 demand = 15-30 lb/ac-d at 1,000 to 2,000 lb/ac
5) Feed of 20- 40 lb/ac-d
6) Marine shrimp yields < 1,000 lb/ac

1) Boyd, C. E. and D. T. Coddington, Relationship between wind speed and reaeration in small aquaculture ponds, Aquaculture Engineering, Vol 11, No 2, 1992, 121-131.
2) Average wind speed at Stoneville MS
3) At 1.5% of body weight
4) At FCR of 2/1, and 200 day growing season

Mechanically Aerated Semi-Intensive Catfish Pond Production

Pond algae treatment
1-2 hp/ac, in 5-10 acre ponds
50-100 lb-feed/ac-d
4,000-7,000 lb/ac fish
1,000-2,600 lb/ac shrimp

[1] Field observed shrimp aeration needs = 1.1-1.5 x O_2 demand in 1 acre ponds to 2-3 x in 10 acre ponds

Example; commercially available 1-2 hp/ac

[1] Garcia, A, and D.E. Brune, 1991, Transport Limitation of Oxygen in Shrimp Culture Ponds, 10:269-279, *Aquacultural Engineering*.

Intensive Freshwater Catfish

Mixed treatment;

Enhanced algal + nitrification

2.0 acres water, 5.5 ft deep

6-10 hp/ac aeration capacity

6 hp/acre x 24 hrs x 50% = 72 hp-hr x 1.5 lb O_2/hp-hr = 108 lb-O_2/ac-d

Fish density = 108 lb @ 0.017 lb O_2/lb fish = 6,350-12,700 lbs/ac capacity = 2.6 – 5.3 hp/ac-d [1]

Feed =20,000-28,000-lb/season = 100-160 lb/ac-d = 2.6- 4.4 hp/ac

[1] Boyd, C.E., S Chatvijitkul, and D. A. Davis, Understanding oxygen demand of aquafeeds,

Intensive Marine Shrimp Ponds

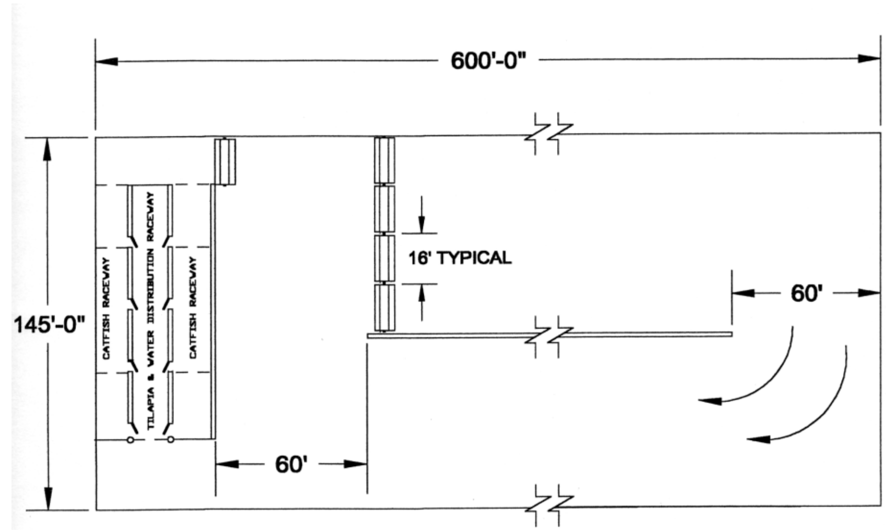
Stocking = 100-150/m^2
Yields = 8,000-12,000 lb/acre-100-130 days
Feed/organic rate = 100-200 lb/ac-day
Aeration = 15-30 hp/ac
Capital = $60,000- $150,000/acre
Microbial type = algal/heterotrophic or algal/nitrifying
Water depth = 5-6 ft
ADVANTAGES = Lowest cost intensive production
DISAVANTAGES = Marine tropical location needed, water input /discharge or treatment ponds needed, potential environmental impacts, production intensity limited by water mixing and solids sedimentation

Aquasol consultants, FL

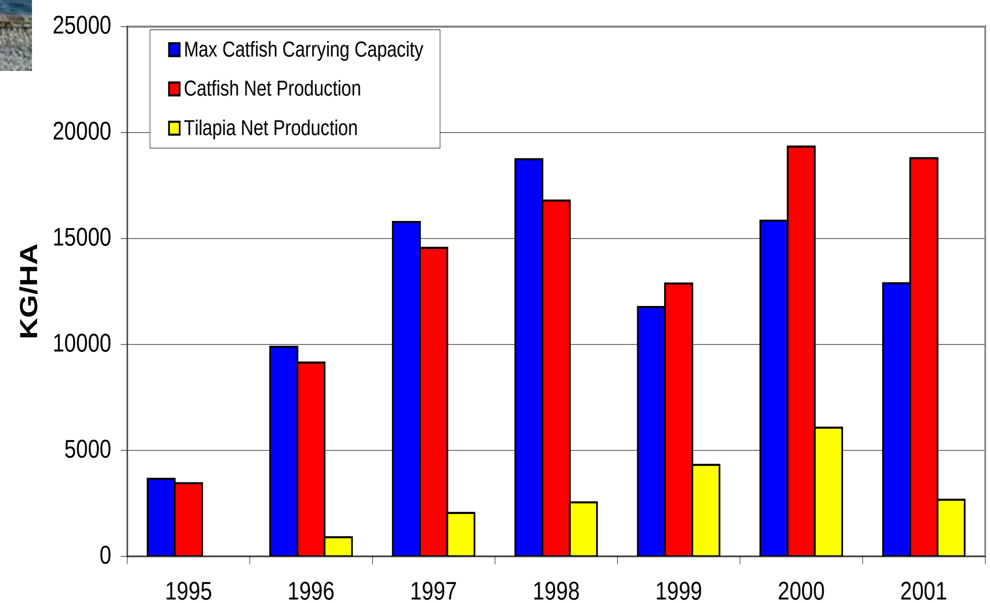
Coastal Belize

Marine Shrimp, China

Partitioned Aquaculture System;
Enhanced Algal Treatment in “High-Rate Ponds”



7-10 hp/ac
100-280 lb-feed/ac-d
15,000-18,000 lbs/ac yield
Tilapia co-culture for algal species and density control



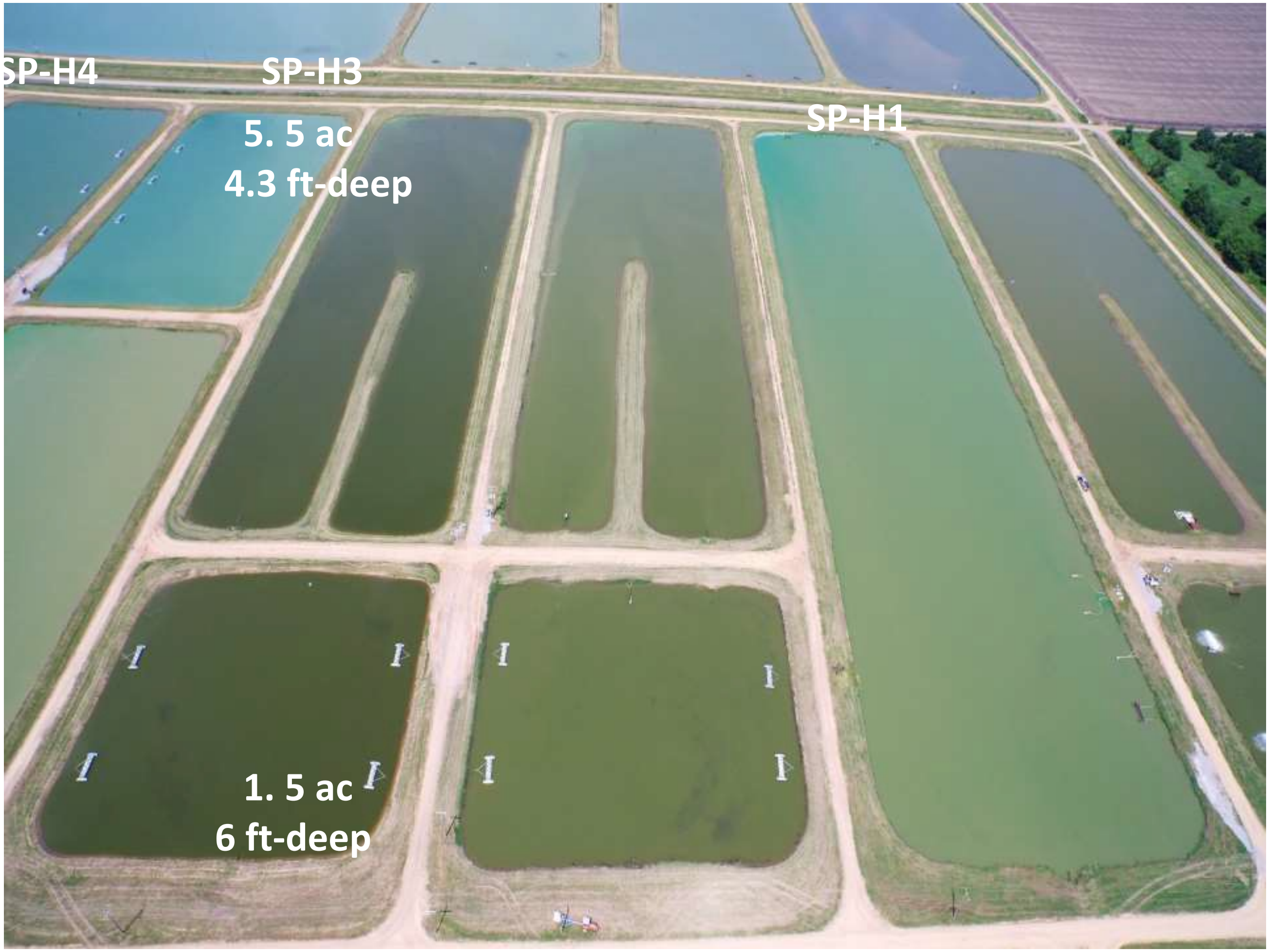
MS Split-Ponds Freshwater Catfish; Enhanced Algal Treatment, at Reduced Cost

6-20 hp/ac

14,000 lb/ac typical production

120-280 lb/ac-d feed
7-20 acres with 25% fish culture volume

Paddles and screw pumps to move water



Super-Intensive Shrimp Production in Tanks

Stocking = 200-400/m^2
Yields = 25,000-45,000 lb/acre-100-120 days
Feed/organic rate = 400-1000 lb/ac-day
Aeration = 60-100 hp/ac
Capital = highly variable
Microbial type = heterotrophic or nitrifying (indoor)
ADVANTAGES = Flexible size of operation, control over inventory and harvest schedule, multiple batch production, independent/isolation possible, zero-discharge, good learning platform
DISAVANTAGES = Not hydrodynamically scalable, Low water surface area to enclosure ratio, Not well suited to automation

Dairyland Shrimp LLC, Wisconsin, Heterotrophic biofloc, saltwater zero-water exchange, clarifying tanks, 120 day grow-out to 20 gram shrimp

Blue Oasis Shrimp, Las Vegas, Water treatment not described, out of business 2016?

The Drive to Limited/Zero-Discharge Aquaculture

Animal agriculture recovers only a small fraction of feed-N

79 - 88% nitrogen discharged as pollutant

Soy, corn & fish-meal nitrogen inputs

12 - 21% protein nitrogen converted to fish or shrimp

In limited or zero-discharge aquaculture , ammonia-N must be treated, recovered , or disposed of using one or more of three techniques;

Algal Photosynthesis (Green Water; Requires Sunlight)

$NH_4 + CO_2 = C_{106}H_{263}O_{110}N_{16}P$ (Algal Biomass) $+ 106\ O_2$

Bacterial Nitrification (Autotrophic Biofloc; Slower Growth)

$NH_4 + O_2 = C_5H_7O_2N$ (Bacterial Biomass) $+ NO_3 + CO_2$

Heterotrophic Bacteria (Brownwater; Requires Carbohydrate)

$NH_4 + C_6H_{12}O_6$ (Sugar) $+ O_2 = C_5H_7O_2N$ (Bacterial Biomass) $+ CO_2$

Algal and heterotrophic = yields large quantities of microbial biomass (~12,000+ lbs/acre dry sludge/cycle)

The solution; recover, convert microbial biomass to food, feed, fuel, and fertilizers

Photosynthetic or Algal System With Bioprocessing of Solids

Feed

Nitrogen Waste

Algal Biomass
300 lb max feed/ac-day

Food and Feed

Bioenergy

Brine shrimp as fish meal replacement

Slow Release Biofertilizer

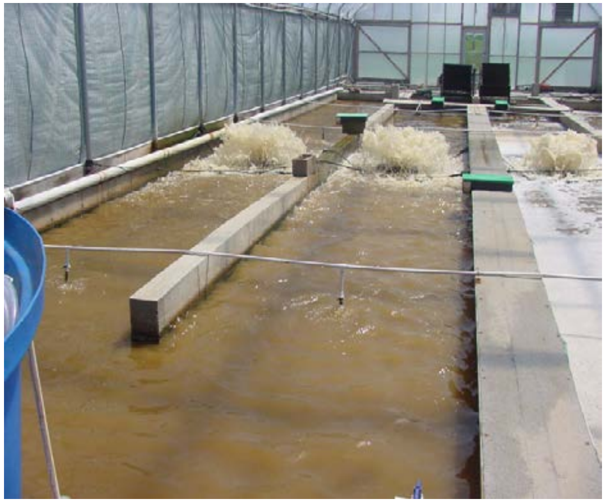
Heterotrophic System (30,000- 45,000 lb/acre yield)

Bioprocessing for solids control
Zero discharge, feed co-production

Feed

Nitrogen Waste

Bacterial Biomass



Carbohydrate addition

Bead filter processing for solids control
Two water exchanges/cycle
Sludge disposal needed

Nitrifying/Denitrifying (Autotrophic Bacterial) With Bioprocessing of Solids

Feed

Nitrogen Waste

Bacterial Biomass Feed C/N = 9/1; 35%P

Biofloc;10% solids production of heterotrophic

Food and Feed

Brine shrimp

Non Polluting Gases

N_2 & CO_2

Slow Release Biofertilizer

Overview of Aquaculture Intensification [1]

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From 2,000 lb/acre Farming to 40,000 lb/acre Industrial Food Production

[1] Brune, D. E., Autotrophic and Heterotrophic Water Treatment in Semi-Intensive, Intensive and Super-Intensive Fish and Shrimp Culture, *The Shrimp Book*, Victoria Alday-Sanz, Editor, Nottingham University Press, In Press 2021.

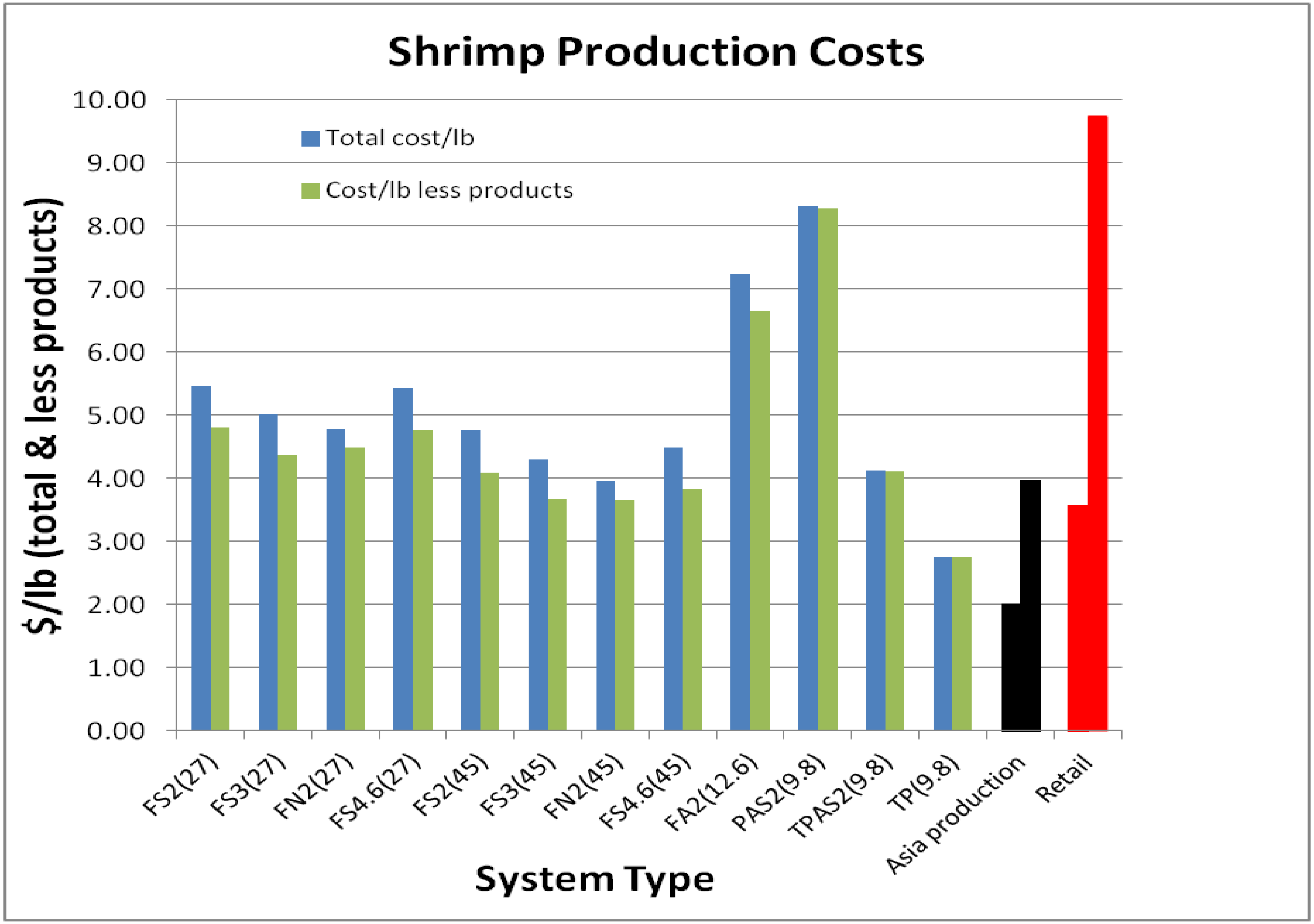
Production Cost 12 systems

Culture cost $/lb (blue)

$/lb less co-product value (green)

Asian intensive pond $/lb high/low (black)

Retail price high/low (red)



Intensive to super-intensive production costs at the upper edge of open pond production costs, but well within retail prices. Consumer is driver in selecting more environmentally friendly, sustainable production at higher prices