

# **OXYGEN AND NITROGEN DYNAMICS IN ENHANCED CATFISH PRODUCTION SYSTEMS**



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## Overview of Aquaculture Intensification (1)

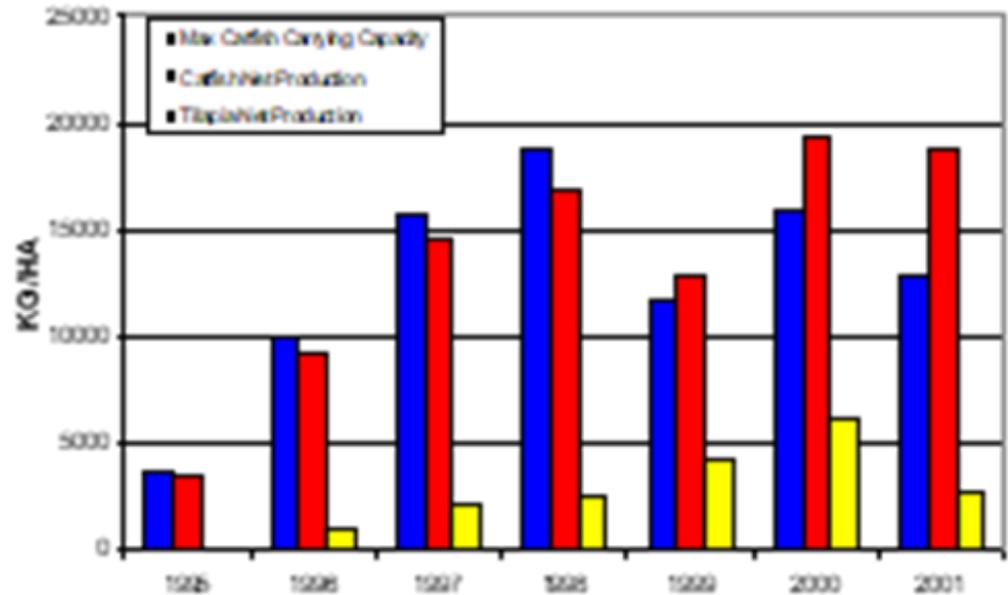
Name, Yield, Feed, Aeration, Solids, Microbial Type, Solids, Inception date

<b>SYSTEM</b>	<b>Yield lb/ac</b>	<b>Feed lb/ac-d</b>	<b>Aeration hp/ac</b>	<b>Type g-C/m<sup>2</sup>-d</b>	<b>VSS mg/l</b>	<b>Timeline</b>
Extensive	1,000-2,000	10-30	Wind	Algal (0.5-1)	10-20	1960
Semi- Intensive	4,000-6,000	50-100	1-2	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	Algal (6-12)	50-100	2000
Super heterotrophic	40,000+	1,000/600	60-80	Heterotrophic	300-400	2006
Super nitrifying	40,000+	1,000	50-60	Nitrification	300-400	2006
Rapid Removal	30,000-44,639	1,500	67-76	Intense Nitrification	70-80	2020

Aquaculture technology has advanced over 60 years; Fish/shellfish yields increased from farm-pond production of 1,000 to 2,000 lbs/acre-year to 40,000 to 50,000 lbs/acre-year in, year-round, climate-controlled, zero-discharge, recirculating aquaculture systems (RAS).

(1) Brune, D. E., Autotrophic and Heterotrophic Water Treatment in Semi-Intensive, Intensive and Super-Intensive Fish and Shrimp Culture, *The Shrimp Book II*, Victoria Alday-Sanz, Editor, 5M Press, 2022.

## Enhanced Catfish Production Systems; PAS



The Clemson **Partitioned Aquaculture System** (PAS, 1987-2001) demonstrated 10,000 –18,000 lb/acre-yr production in 0.3-2.0 acre high-rate algal ponds linked to catfish culture in raceways comprising 5% of total pond area<sup>(2,3,4,5)</sup>

## Enhanced Catfish Production Systems; SP



**Split-Ponds** (SP, 2005-2020) at National Warm-Water Aquaculture Center (NWAC)/Mississippi State University (MS) demonstrated 12,000–19,000 lbs/acre-yr catfish production in 5.0-7.0 acre ponds divided into water treatment and fish culture zones, with fish confined to 20-25% of pond area<sup>(6,7,8)</sup>

## Enhanced Catfish Production Systems; IP



**Intensively aerated ponds** (IP) at NWAC/MS (2014-2018) demonstrated 9,000–15,000 lb/acre-yr catfish production in 1.0-4.0 acre ponds with fish confined to 100% of pond area<sup>(9)</sup>

## Enhanced Catfish Production Systems; IPR



**In-Pond Raceways** (IPR) at Auburn University (2006-2017) demonstrated 18,300 lb/acre catfish production in 6.0 acre pond with fish confined to 2.0% of pond area<sup>(10,11)</sup>

## Representative Culture Footprint, Aeration Energy, and Yield of Enhanced Catfish Production

System	Fish Culture	Typical Acres	Aeration energy hp/ac	Yield Range lb/ac
PAS	5%	2.0	6.0	17,000-19,000
SP	20%	7-10	6-10	13,000-17,000
IP	100%	5 -7	6-10	7,000-17,000
IPR*	2%	6	3.0	13,400
CP	100%	5-10	3.3	5,000-8,000

Average PAS production is highest, followed by SP, IP, IPR and CP. Observed fish production in IP is more variable than in SP<sup>(12,13)</sup>

\* IPR highly variable

## Enhanced Catfish Production Systems; Projected Investment, Yield, Break-Even Cost, and (2019) Industry Adoption

	Capital \$/acre	Yield lb/ac	BE Cost \$/lb	Industry Fraction
PAS	32,000	17,000	1.46	< 1.0%
SP*	7,262	21,258	0.92	7.8%
IP*	5,894	14,989	0.93	39.5%
IPR	22,630	9,463	1.32	<1.0%
CP	4,870	4,800	1.05	52.7%

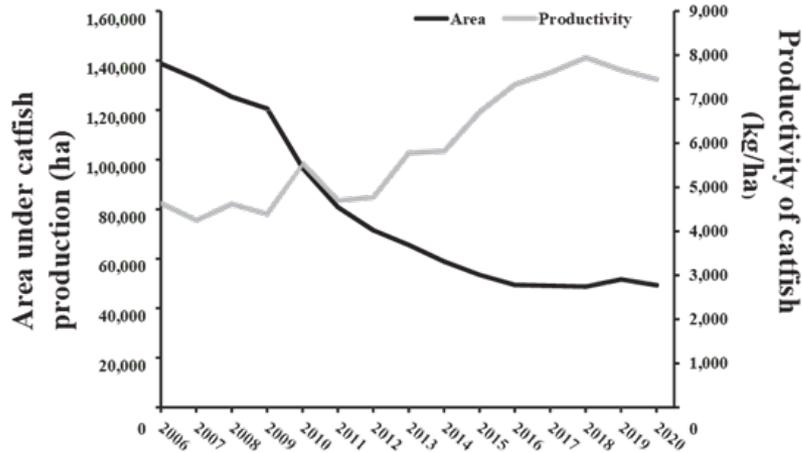
PAS and IPR highest capital and break-even costs.

SP and IP significantly less capital cost, with similar BE.

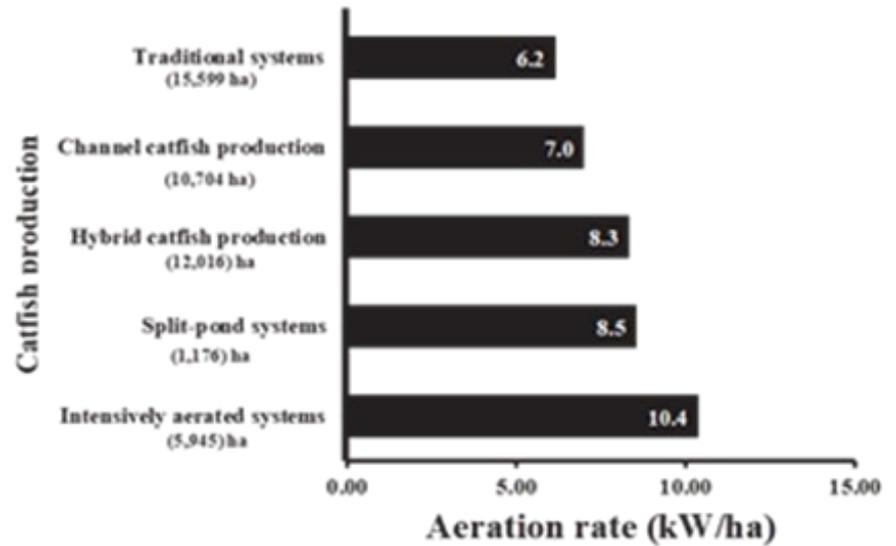
CP lowest investment cost with BE similar to SP/IP depending on level of productivity.

\*2019 industry average at 9,766 lb/acre using enhanced systems (SP+IP) vs 7,672 lb/acre using non-enhanced ponds<sup>(13,14,15,16,17,18)</sup>

# Catfish Industry Intensification; Area and Energy Usage

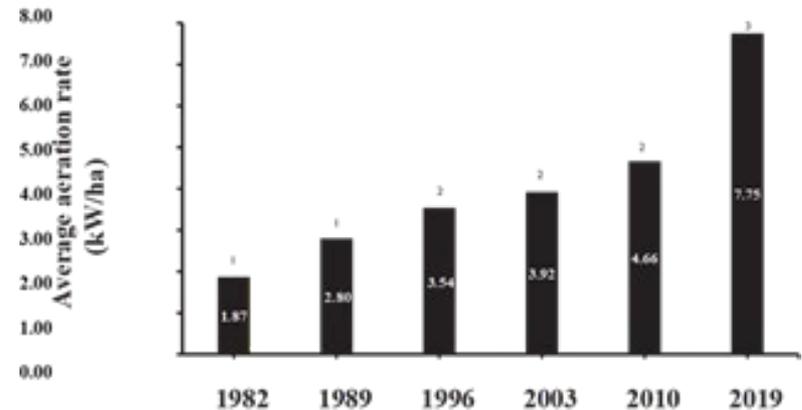


Production Area and Fish Productivity in the U.S. Catfish Industry



Catfish industry; Culture area decreasing 60%; Productivity increasing 160% over 14 yrs

Industry average pond aeration at 5.6 hp/acre for IP vs 3.3 hp/acre for CP<sup>(13)</sup>



## **Advantages of Aquaculture Intensification**

Increased efficiency of water, land and equipment/lb-production

Reduced cost/lb-production

Reduced labor needs/automation possible

Reduced fish predation

Improved fish health management and FCR

## **Limitations/Disadvantage of Aquaculture Intensification**

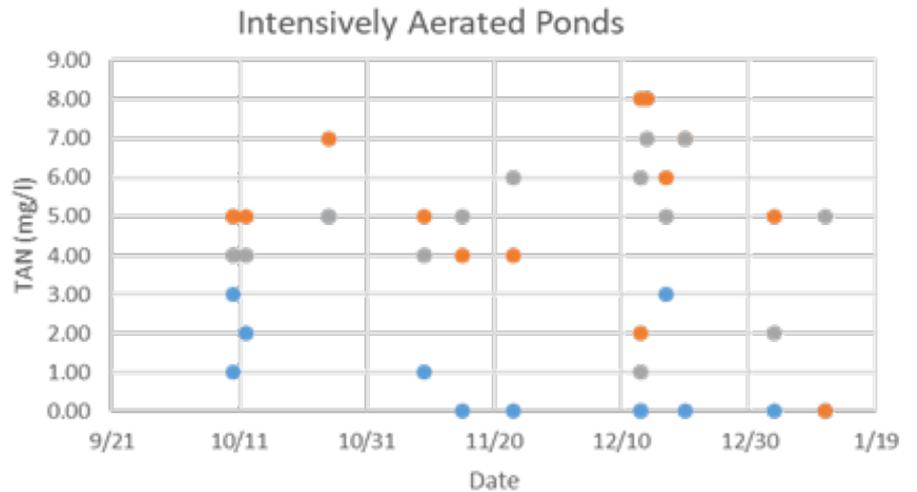
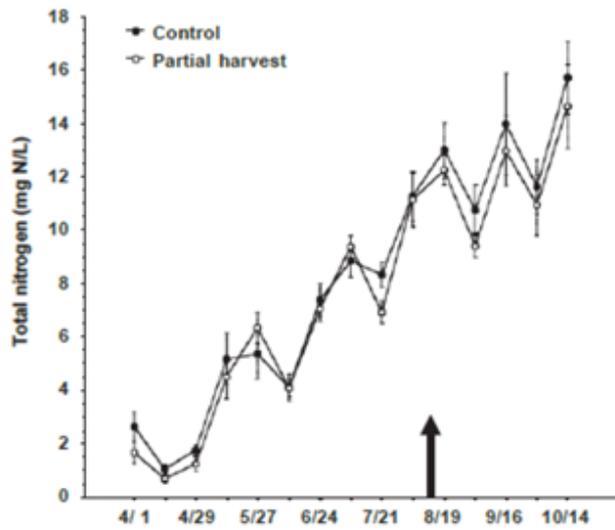
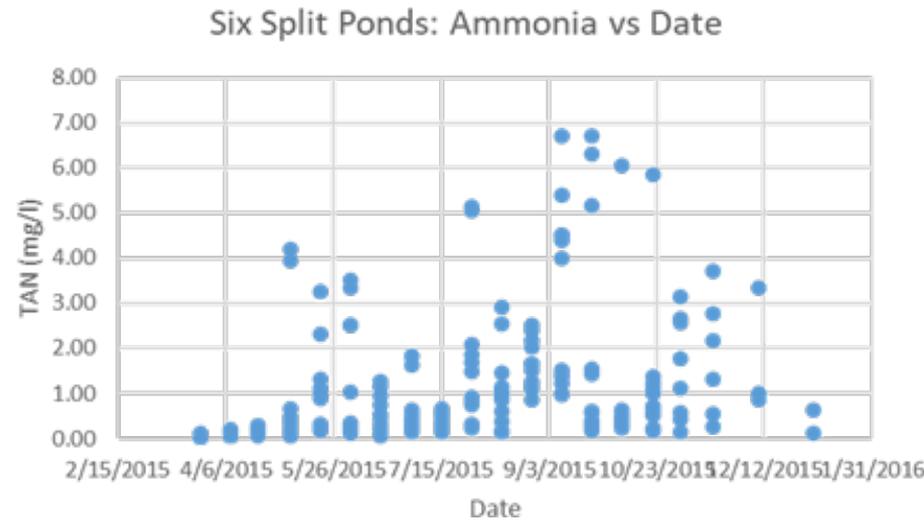
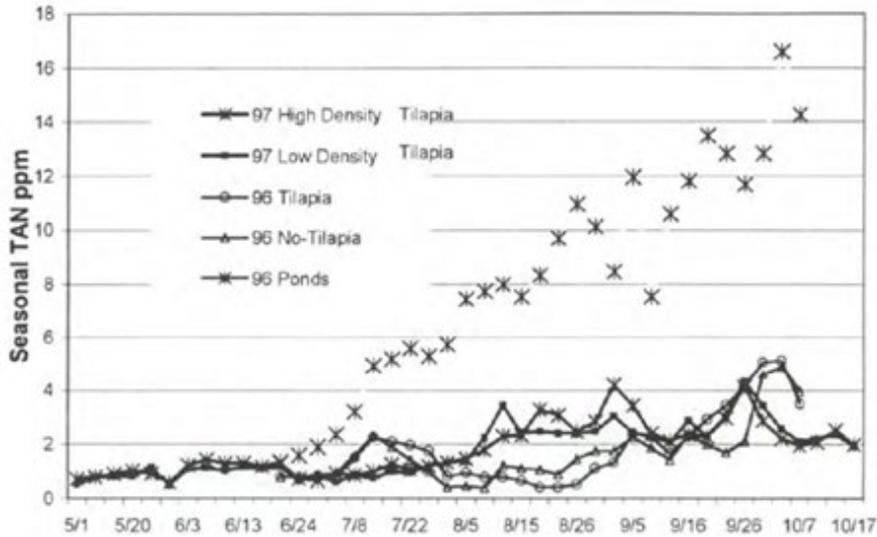
Maintaining control of water quality; nitrogen/ammonia concentrations

Increased dependency on electrical supply (backup generators)

Increased level of technology and training of labor

Capital intensive, increased investment

# Ammonia Concentrations in Enhanced Catfish Production Systems



Total ammonia nitrogen levels in PAS and SP typically < 4.0 mg/l: Evaluated levels of nitrogen and ammonia (> 4.0 mg/l) observed post fish-harvest in conventional ponds and IP<sup>(8,17,18,19)</sup>

# Photosynthesis and Nitrogen Uptake in Enhanced Catfish Production Systems

Type	Catfish N-loading (lbs-N/acre-day)	Sediment N-recycle (lb-N/ac-d)/(%fish)	Photosynthetic N-uptake (lbs-N/acre-day)	Nitrification (% of photo)
PAS	+6.1	+ 5.8 (94%)	-11.9	0%
SP	+5.0	+ 3.7 (74%)	-8.7	20%
IP	+6.9	+ 3.6 (52%)	-10.5	0%
CP	+2.2	+0.5? (23%?)	- 2.2	0 % ?

Type	Gross Photosynthesis (lb-O <sub>2</sub> /ac-d)	Water Column Respiration (lbs-O <sub>2</sub> /ac-d)	Respiration (% of Gross)	Net Photosynthesis (% of fish respiration)
PAS	+240	-60	25 %	120%
SP	+270	-130	46%	78%
IP	+314	-157	50%	66%
CP	+72	-40	55%	64%

PAS, SP and IP are highly photosynthetic.

PAS water column respiration is 50% of SP, IP and CP.

PAS recycles 94% of feed nitrogen vs 74%, 52% and 23 % in SP, IP, and CP.

Significant nitrification observed in SP; limited nitrification in PAS, IP & CP<sup>(20)</sup>

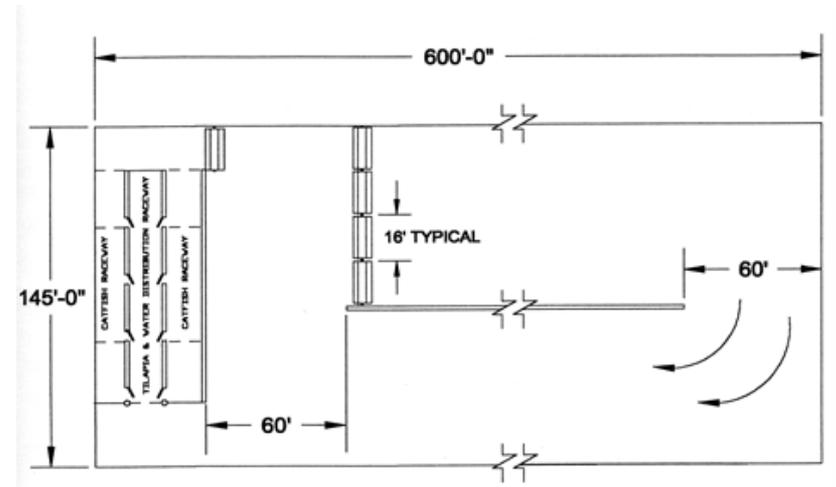
## Algal Density, Removal Mechanism, and Dominant Algal Species of Enhanced Catfish Production Systems

Type	Algal Density Secchi Disk/TSS (cm / mg/l)	Algal removal mechanism (Apparent)	Algal genera
PAS	18 / 80	tilapia/sedimentation	green
SP	13 /110	zooplankton/sedimentation	bluegreen 1
IP	12 / 115	zooplankton/sedimentation	bluegreen 1
CP	13 / 110	zooplankton/sedimentation	bluegreen 2

PAS algal density 70% of SP, IP and CP and dominated by green algae (because of tilapia feeding).

BG algae dominate SP, IP and CP<sup>(20)</sup>

# Functionality of Enhanced Catfish Production Systems: SP vs PAS



Water Treatment 4.3 ft,  
 (72% of total volume)  
 Photosynthesis; Top 30%  
 Aerobic Treatment; Top 65%

Fish Culture 6.0 ft,  
 (28% of total  
 volume)

*Anoxic Treatment; Variable 15%*

*Anaerobic Treatment; bottom 35%*

12,000 gpm  
 5 fish-zone  
 exchanges/day

	Photo	N-Recycle	Nitrification	Sludge Retention
PAS	H	H	L	L
SP	H	H	M	H
IP	H	M	L	H
CP	L	M	L	H

PAS operates with shallow water column/high velocity, and high rate of photosynthesis, **N recycle and storage in tilapia biomass**

SP stores bulk of excreted **nitrogen as settled algal biomass in anaerobic waste treatment zone** providing increased nitrogen treatment (including nitrification), with **improved operator control of ammonia levels within fish culture zone**.

IP and CP store settled algal biomass in fish culture sediments, **more prone to ammonia release within fish culture zone, driven by changing wind/temperature**.

Detailed determination of risk benefit of SP vs IP will required more data on sedimentation and mineralization rates in IP.  
 (21,22)

# Summary

Aquaculture productivity has expanded from 1,000-2,000 lb/acre to **10,000 to 19,000 lb/acre in enhanced outdoor ponds** (PAS, Split-Pond, Intensive Ponds) and in **excess of 40,000 lb/acre in indoor recirculating aquaculture systems (RAS)**

Increased production requires increased aeration energy of **6-10 hp/acre in ponds and 50-80 hp/acre in RAS**

Catfish aquaculture intensification techniques include: Partitioned Aquaculture (PAS), Split-Pond (SP), Intensively Aerated Ponds (IP), and In-pond Raceways (IPR)

**IP (42% of industry) and SP (7.8% of industry) are most cost effective** at break-even production cost of ~ \$0.92 /lb

IP wider variation in yield (8,000-18,000 lb/acre) compared to SP (12,000-18,000 lb/ac)

**PAS provide high rate of photosynthesis**, N-recycle and N-storage in tilapia biomass yielding consistent control of TAN (< 4 mg/l), SP provides more consistent control of TAN as opposed to IP

**IP requires minimal modification of existing ponds**, major cost being addition/maintenance of aerators

**SP requires substantial modification of existing ponds, but provides more predictable increase in fish production and treatment of ammonia nitrogen**

**SP accumulates algal sludge in waste treatment zone** separated from fish culture zone; bulk of settled algal biomass is retained in anaerobic zone **providing increased nitrogen treatment** (including nitrification)

**IP and CP store settled algal biomass in sediment which is prone to ammonia release** within fish culture zone, driven by changing wind/temperature

**Fish farmers report excessive accumulation of ammonia (4-8 ppm) in IP**, particularly late season and post fish harvest.

Detailed determination of **risk/benefit of SP vs IP will required more data** on solids sedimentation and mineralization rates IP and SP.

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## **Presentations/Additional Resources**

### **MU Extension Aquaculture Website**

<https://extension.missouri.edu/programs/aquaculture-extension>

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