Advancements in Aquaculture: Economic Opportunity for Midwest Farmers?

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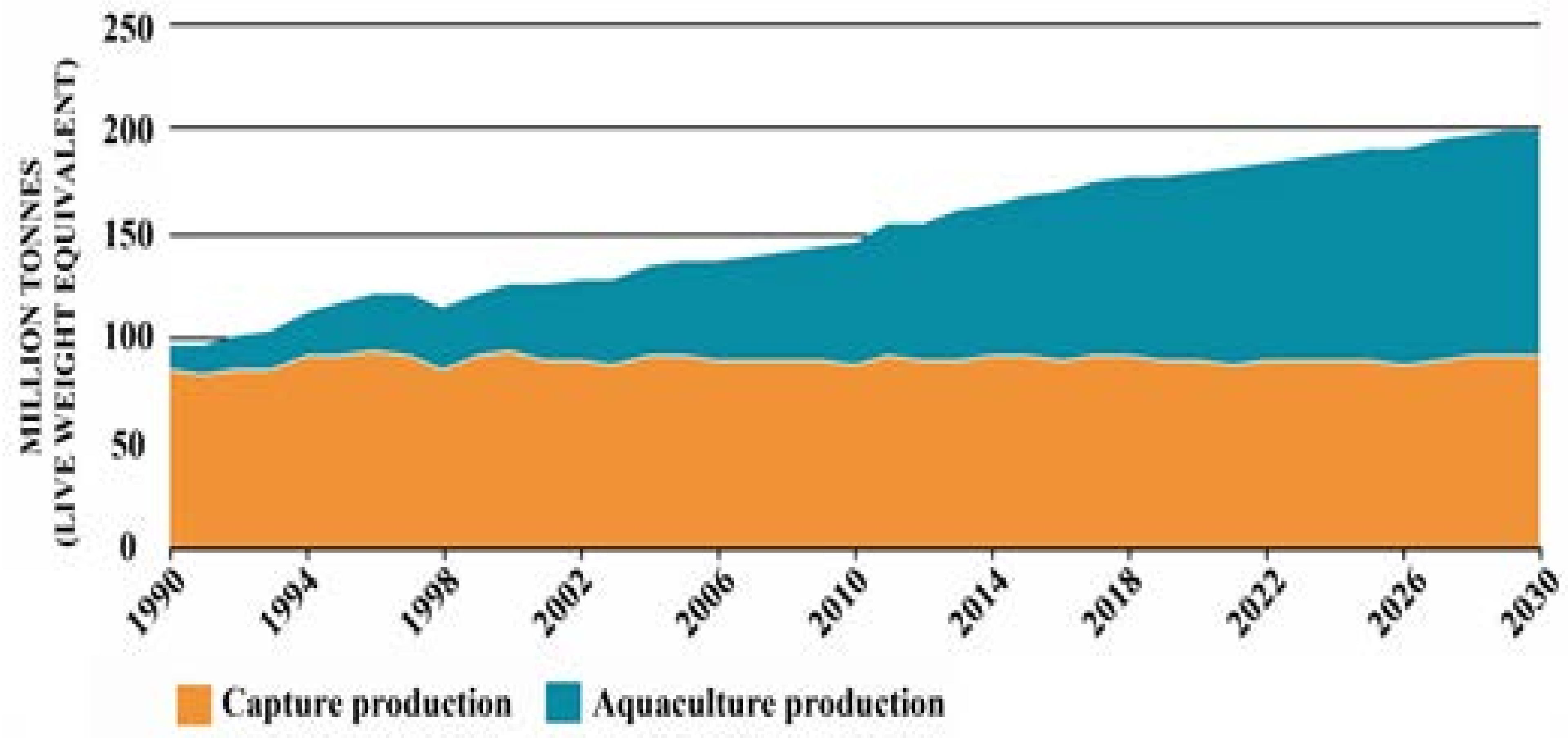
Overview

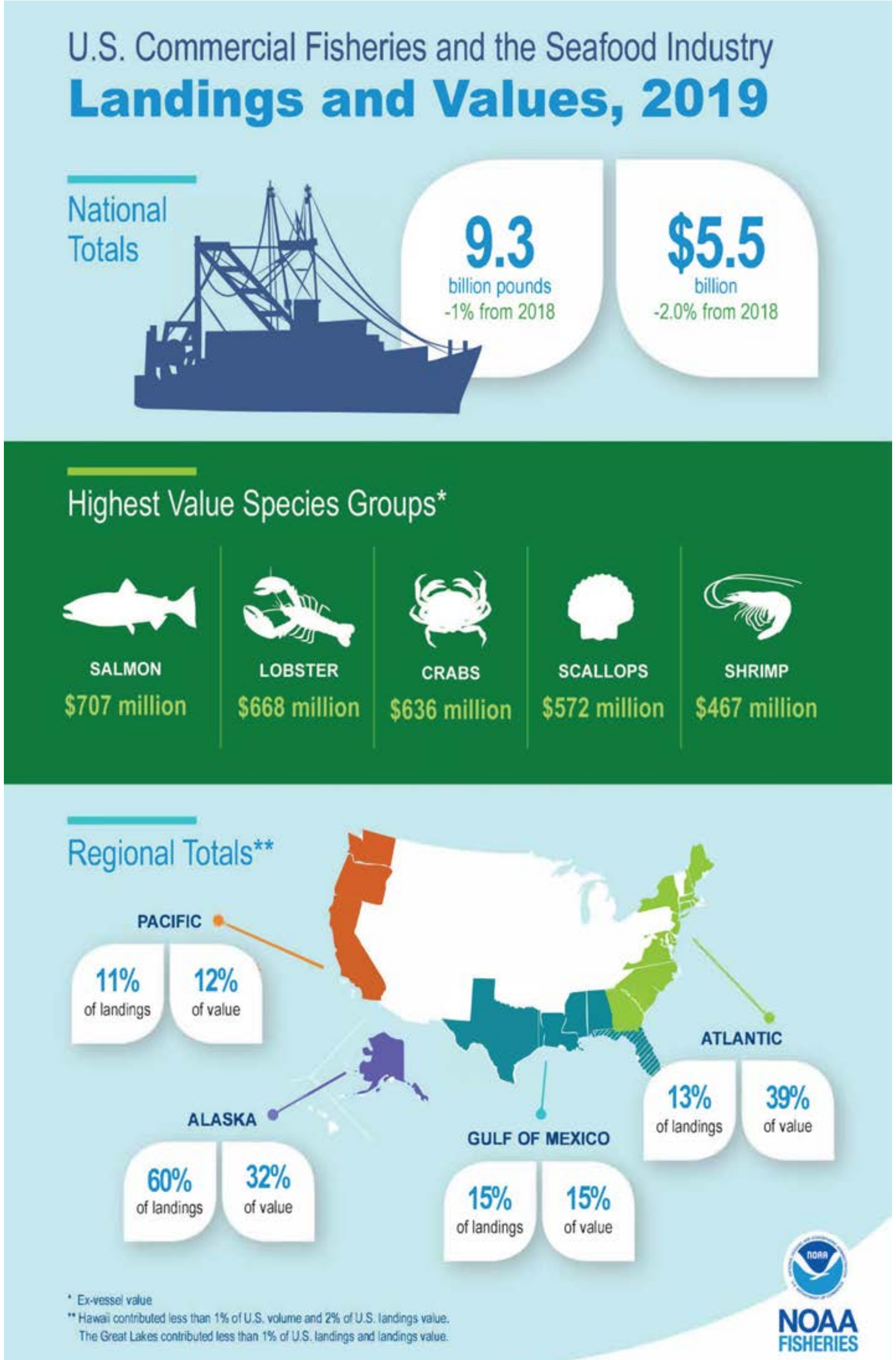
1) Aquaculture by the numbers
2) U.S. catfish production by the numbers
3) Aquaculture intensification
   a) Partitioned aquaculture
   b) Split-ponds, intensive aeration, in-pond raceways
   c) Biofloc shrimp culture
   d) Recirculating aquaculture systems
4) MU-extension funded aquaculture projects
   a) Missouri soybean board
   b) North Central Regional Aquaculture Center
5) Prototype zero-discharge, climate-controlled RAS
6) Aquaculture enterprise budgets/environmental impacts
7) Algal culture and biofuels
8) Catfish fingerling production in PAS

Global Marine and Freshwater Seafood Production

Global Aquaculture Currently Supplies 50%



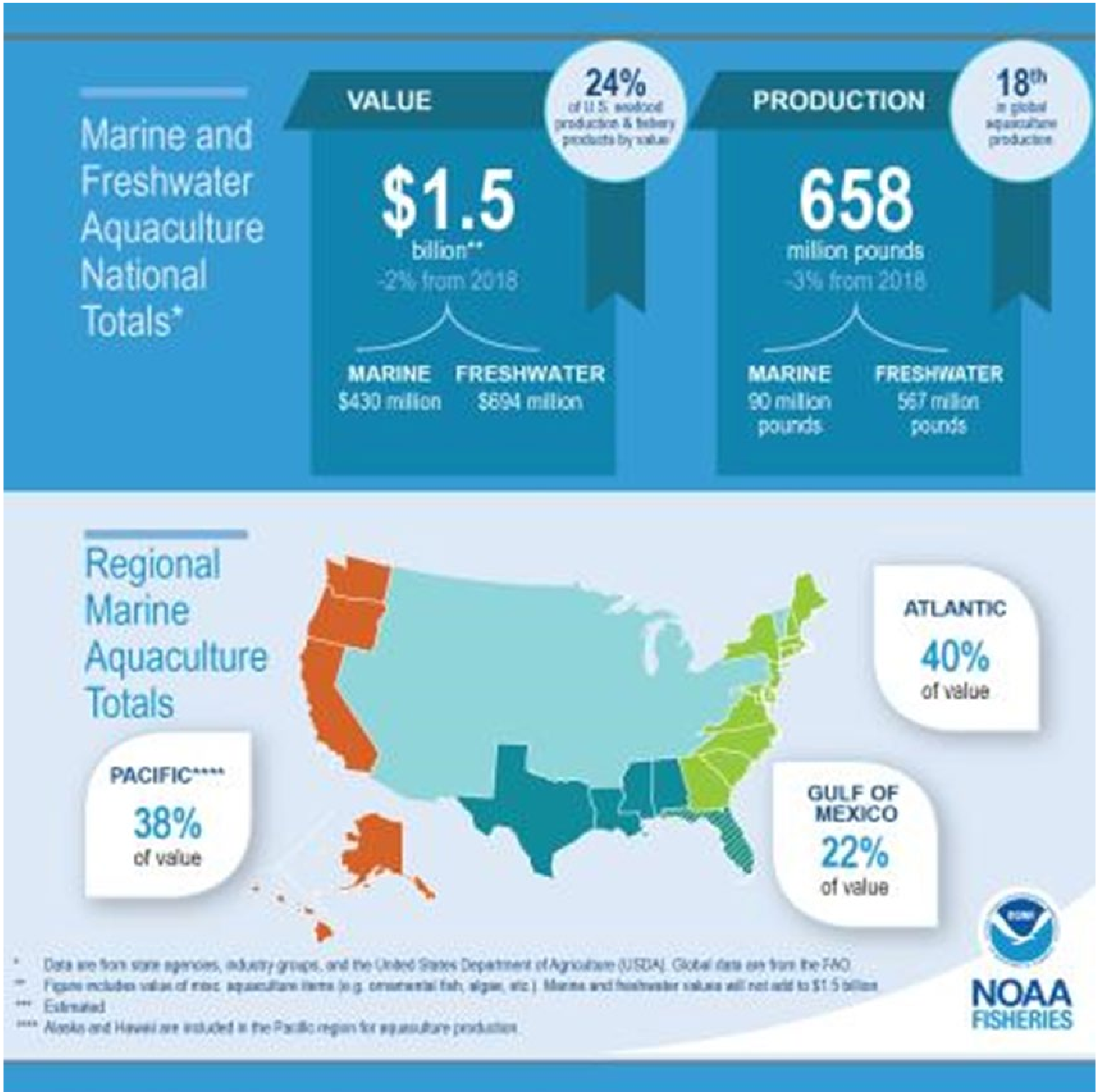
In last 30 years, aquaculture production of marine and freshwater fish/shellfish has grown from 5% to 50% of global seafood supply and is expected to expand. Wild caught fish production cannot be expanded.

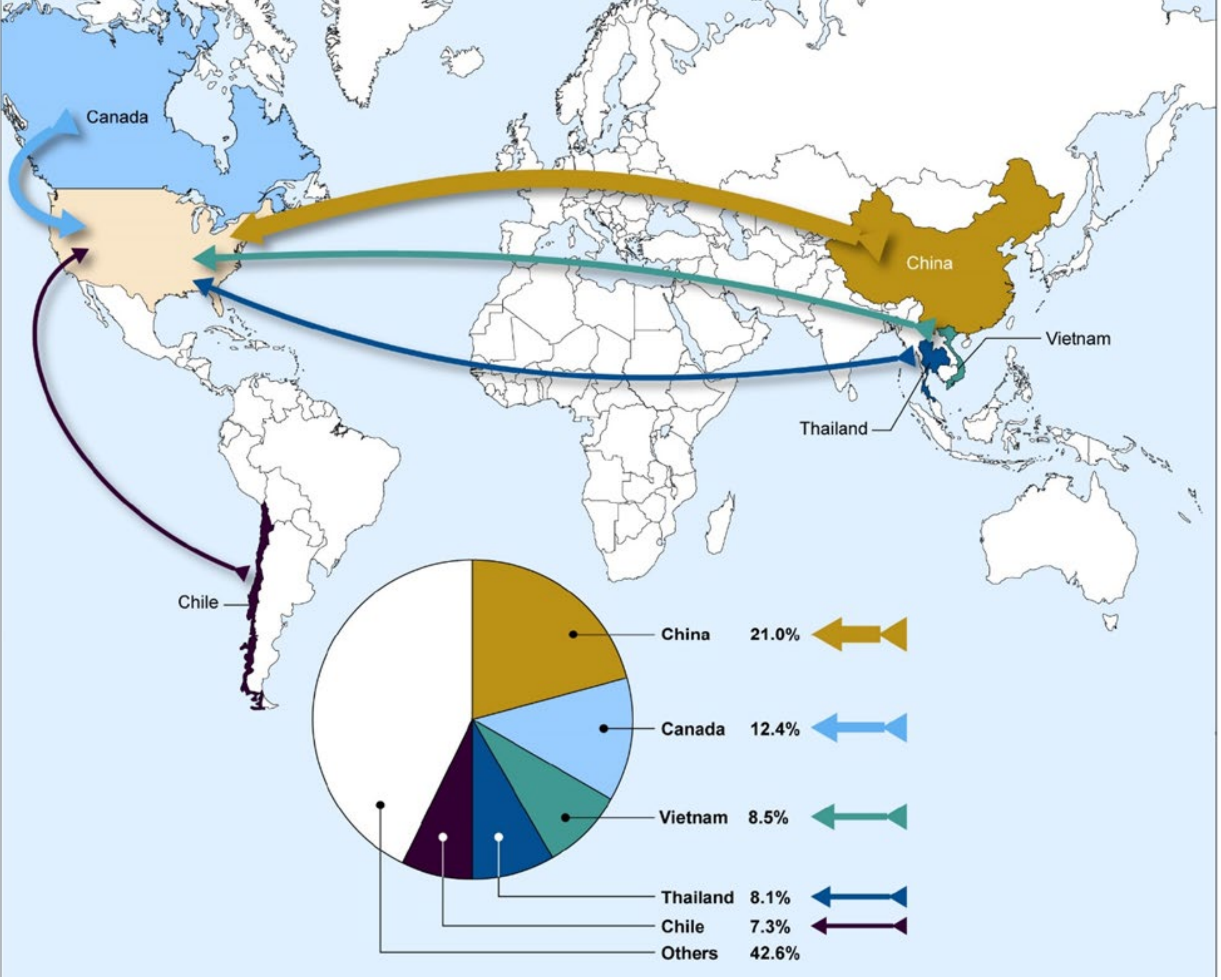


Global Seafood Production; 392 billion lb/yr (2020) of which 192 billion lb/yr was provided by aquaculture (NOAA, 2022).

U.S. Seafood Catch; 9.3 billion lb/yr, with an additional 5.5 billion lb/yr (2019) of seafood product imported.

U.S. Aquaculture Production; Estimated at 658 million lb/yr (7.1% of catch), with U.S. trout at 36 million lbs/yr and U.S. catfish at 307 million lbs/yr (NOAA 2020). Small, but of growing importance





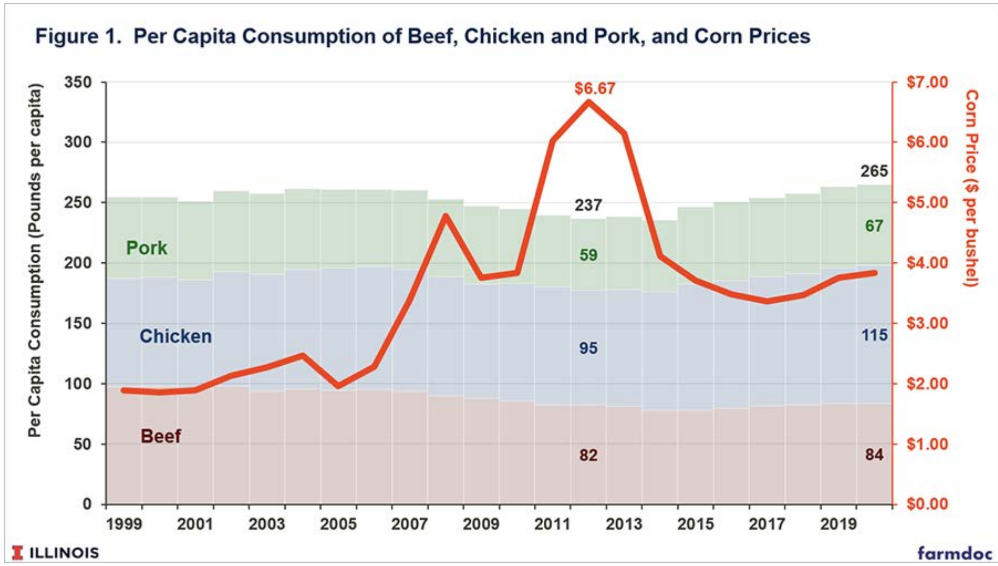
Bulk of U.S. seafood supply is imported

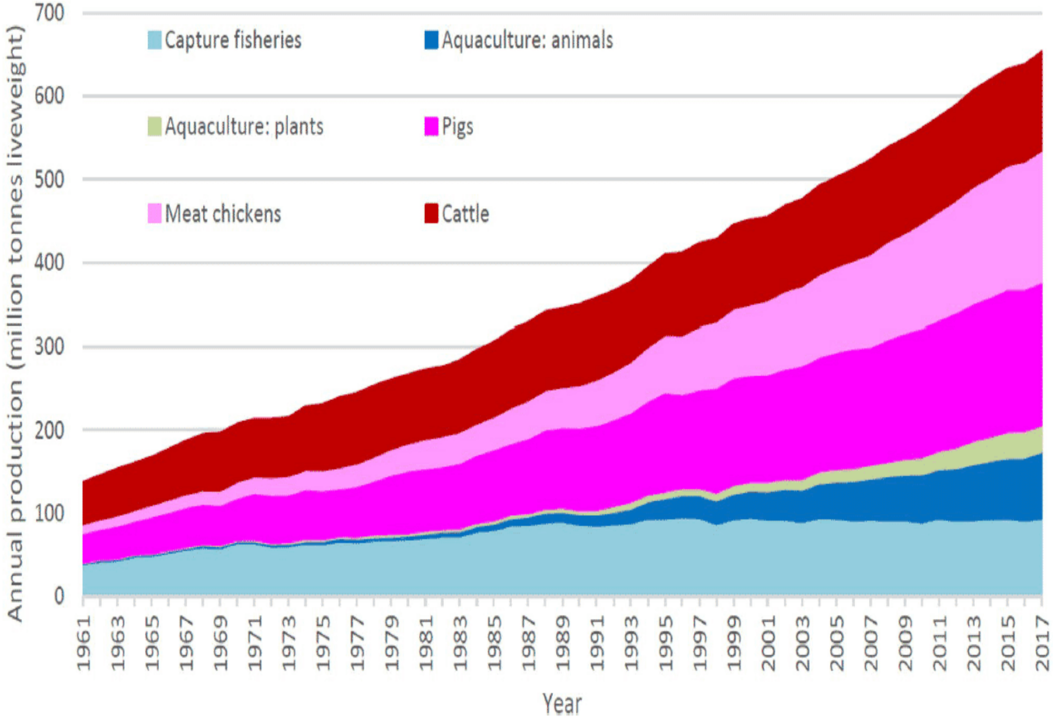
85% of seafood imported
65% caught/grown overseas
25% of US wild caught processed overseas and re-imported to US

85% of U.S. seafood supply is imported, most coming from Asia
U.S. Seafood Trade deficit 2021-2023 = $20.3-24.8 billion

U.S. Per Capital Seafood Consumption, 15-16 lbs/person-yr (6% of livestock consumption) Global consumption, 45.2 lbs/person. Asian, 80-100 lbs/person

U.S. Beef, Chicken, Pork Average Consumption 84 lb-beef/yr, 115 lb-chicken/yr, 67 lb-pork/yr (266 lb/person-yr combined)





Catfish Dominates U.S. Aquaculture Production

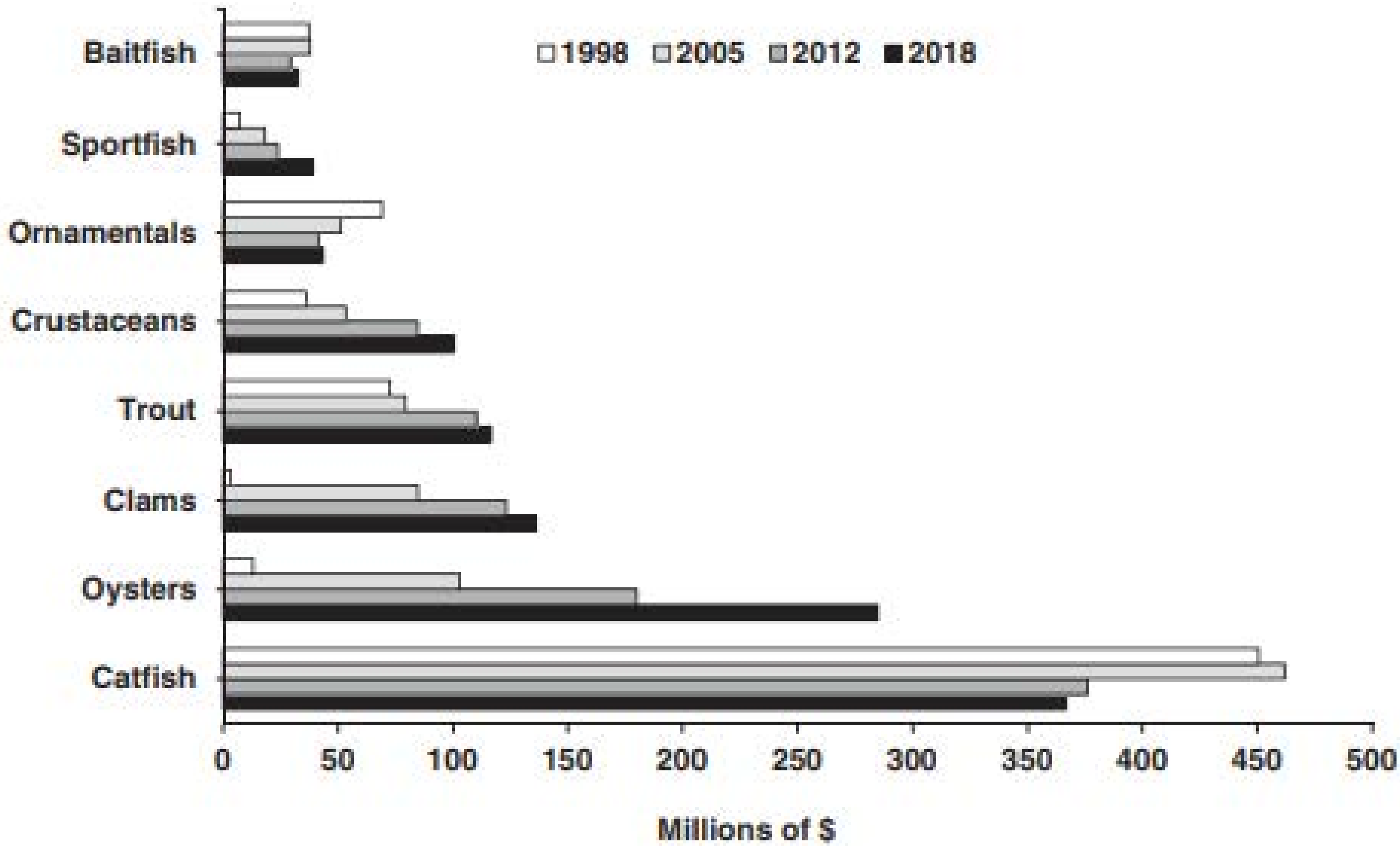


Figure 1. U.S. aquaculture, seven major species categories, by volume of sales, 1998, 2005, 2012, and 2018. Sources: Census of Aquaculture, USDA-NASS.

U.S. Catfish Industry Emerges in 1960's

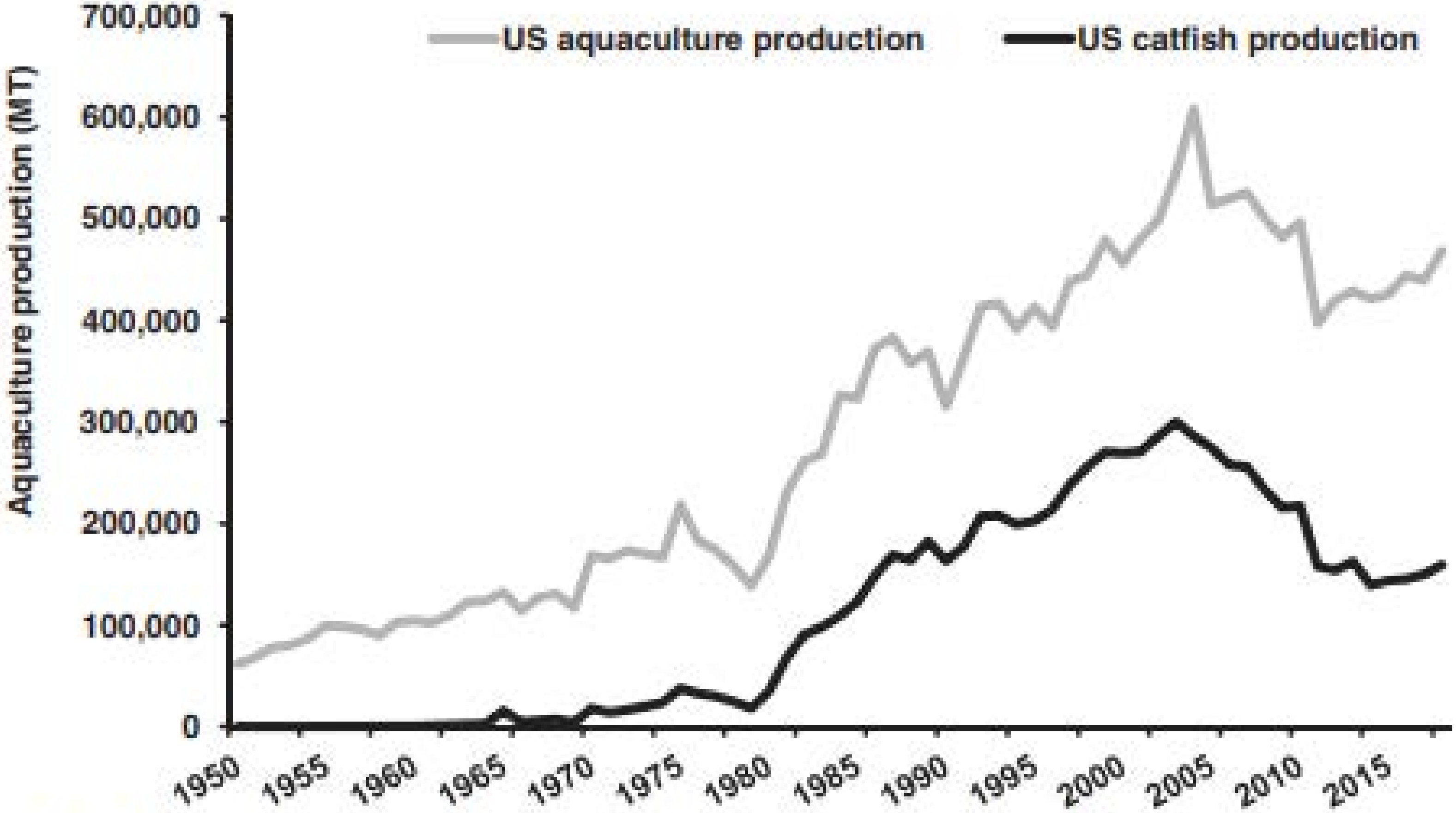
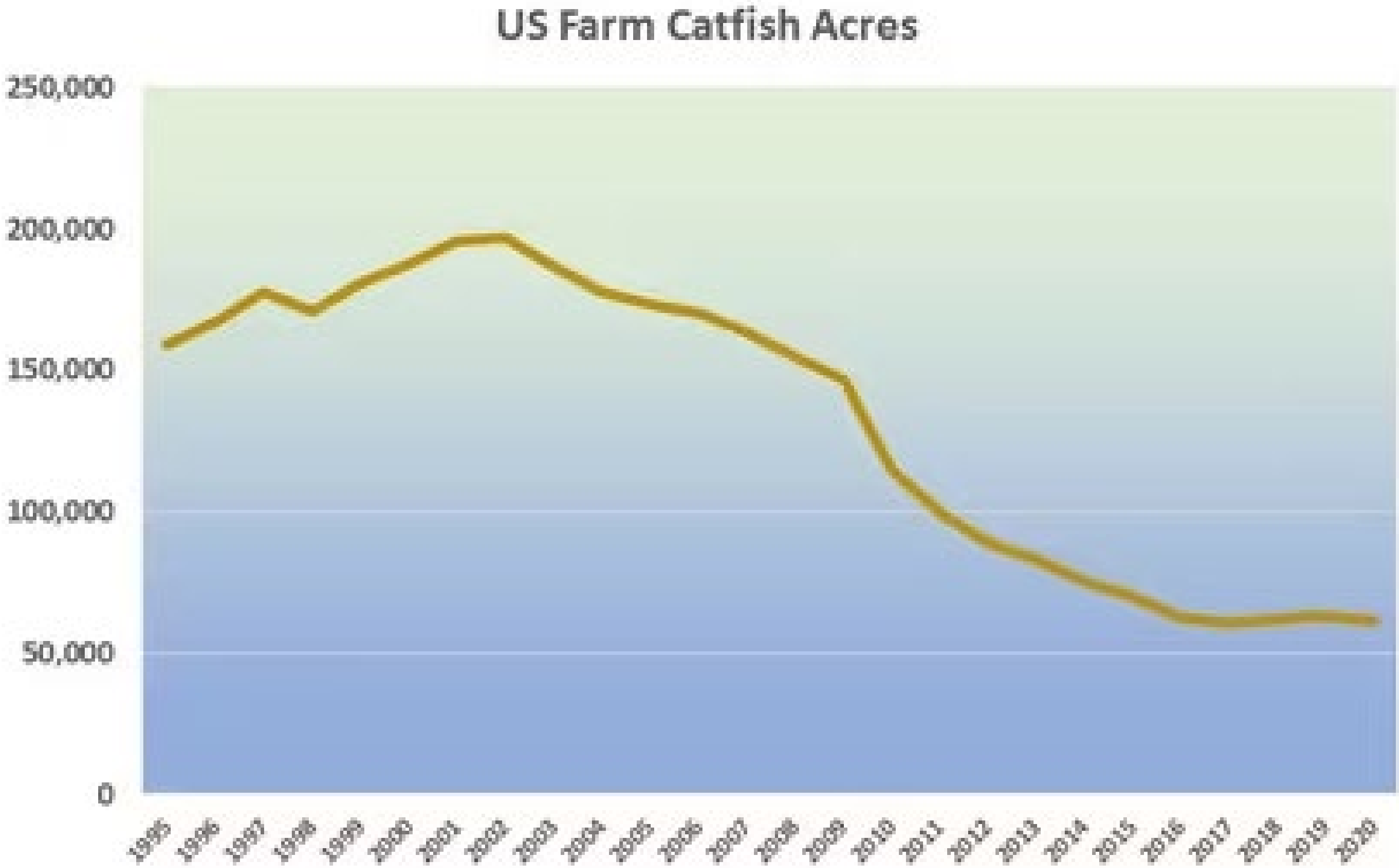


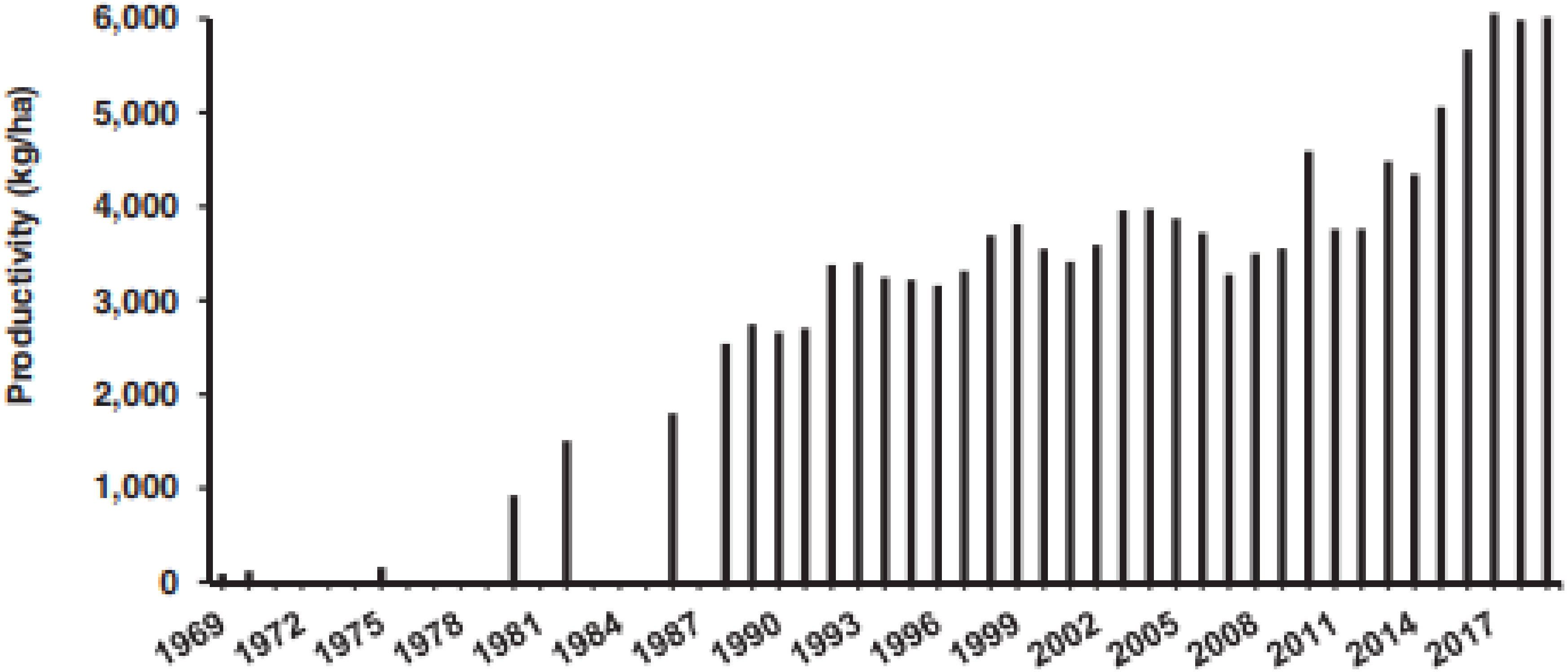
Figure 2. U.S. catfish and total U.S. aquaculture production, 1950–2018 (in metric tons). Source: FAO (2020).

- Seafood consumption downturn beginning in 2001
- Due to NY terror attack, rising feed prices, import competition

Catfish Acres Decline After 2001



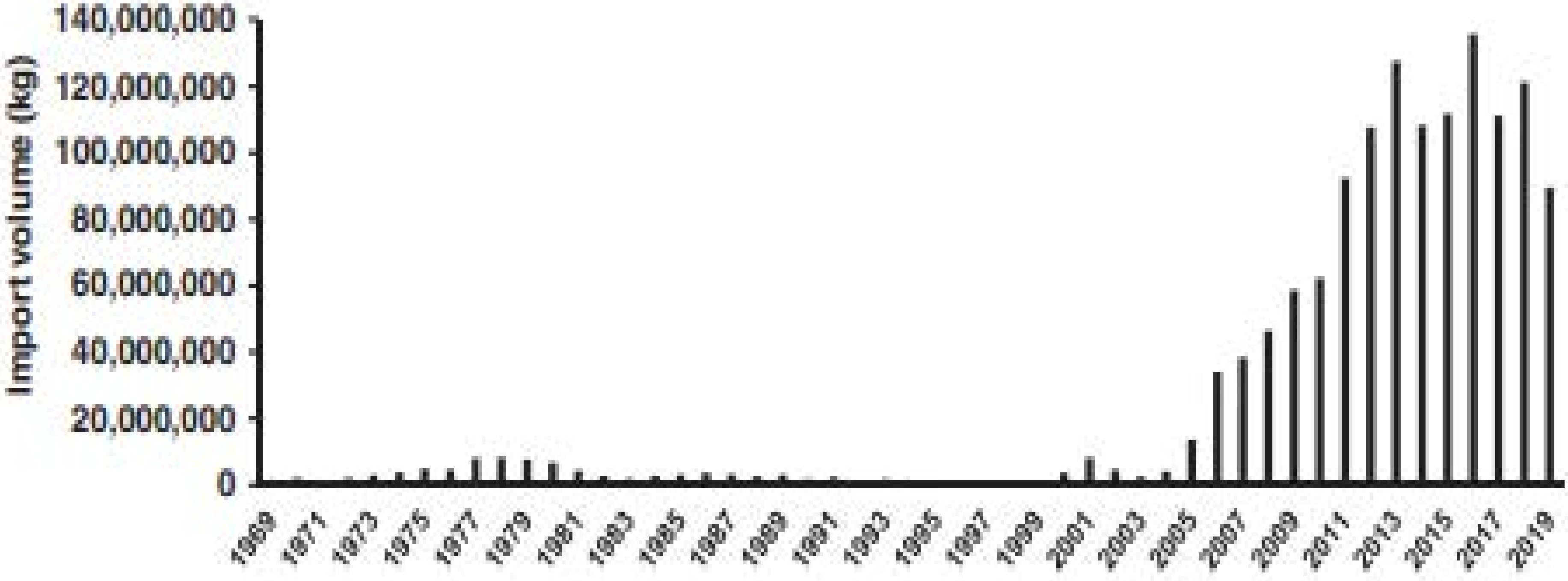
Catfish Productivity (kg/acre) Increases*



*Engle, C., T. Hanson and G Kumar, Economic history of U.S. catfish farming; Lessons for growth and development of aquaculture, Aquaculture Economics and Management, 2022.

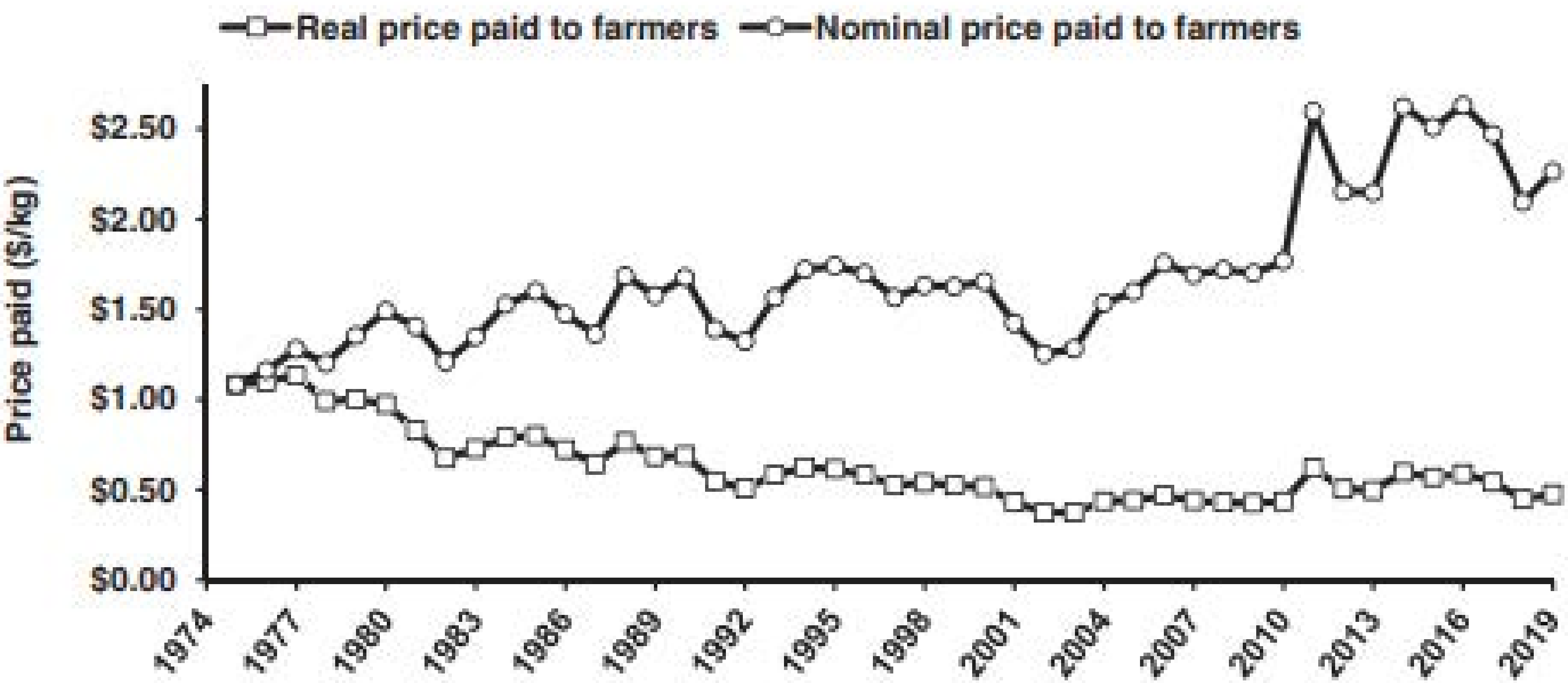
Catfish Imports Increase After 2005*

Asian catfish prices 38-55% lower than U.S. catfish



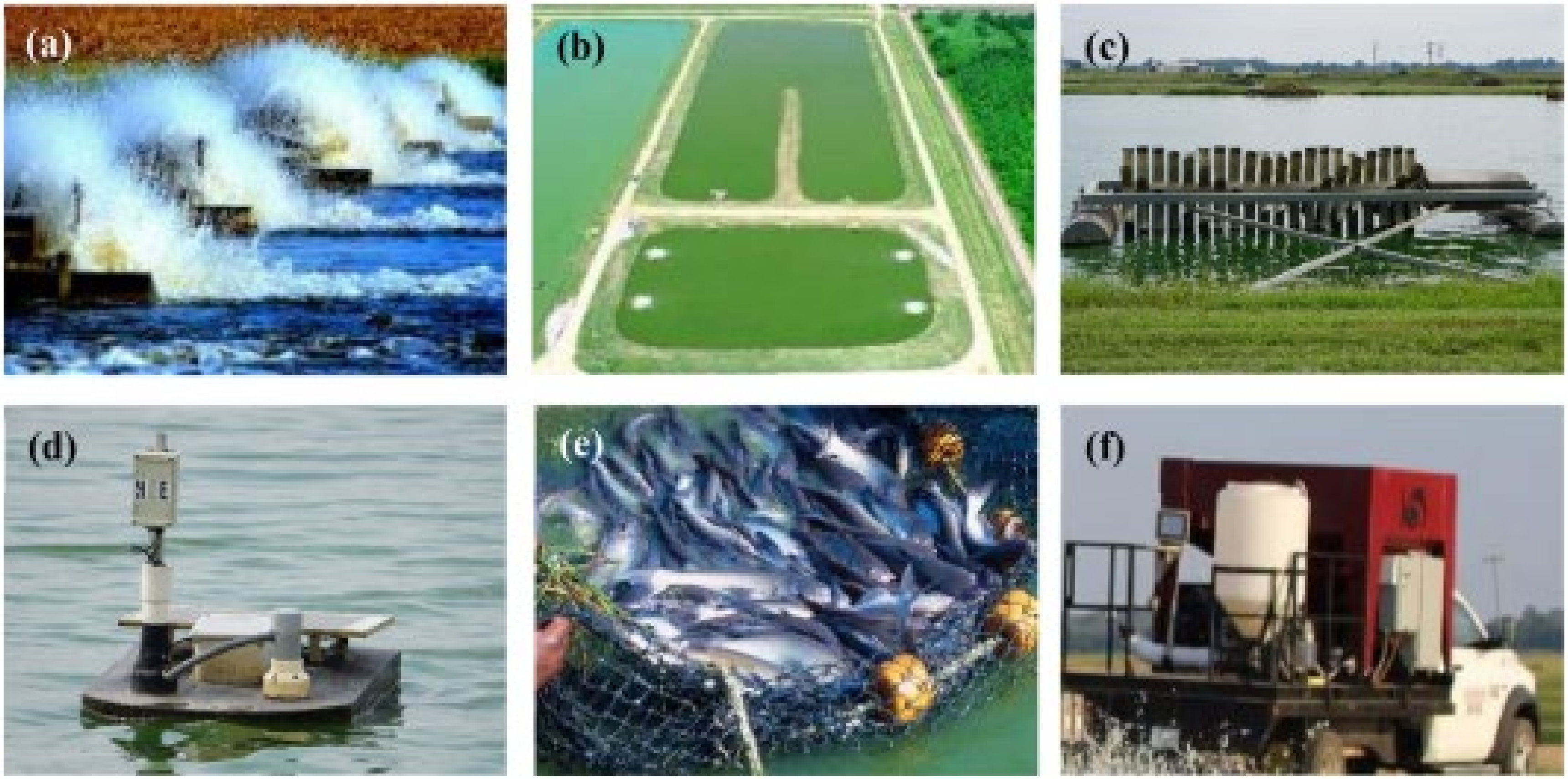
*Engle, C., T. Hanson and G Kumar, Economic history of U.S. catfish farming; Lessons for growth and development of aquaculture, Aquaculture Economics and Management, 2022.

Catfish Farmgate Prices (corrected for inflation) Remains Constant



Increased U.S. Catfish Yields*

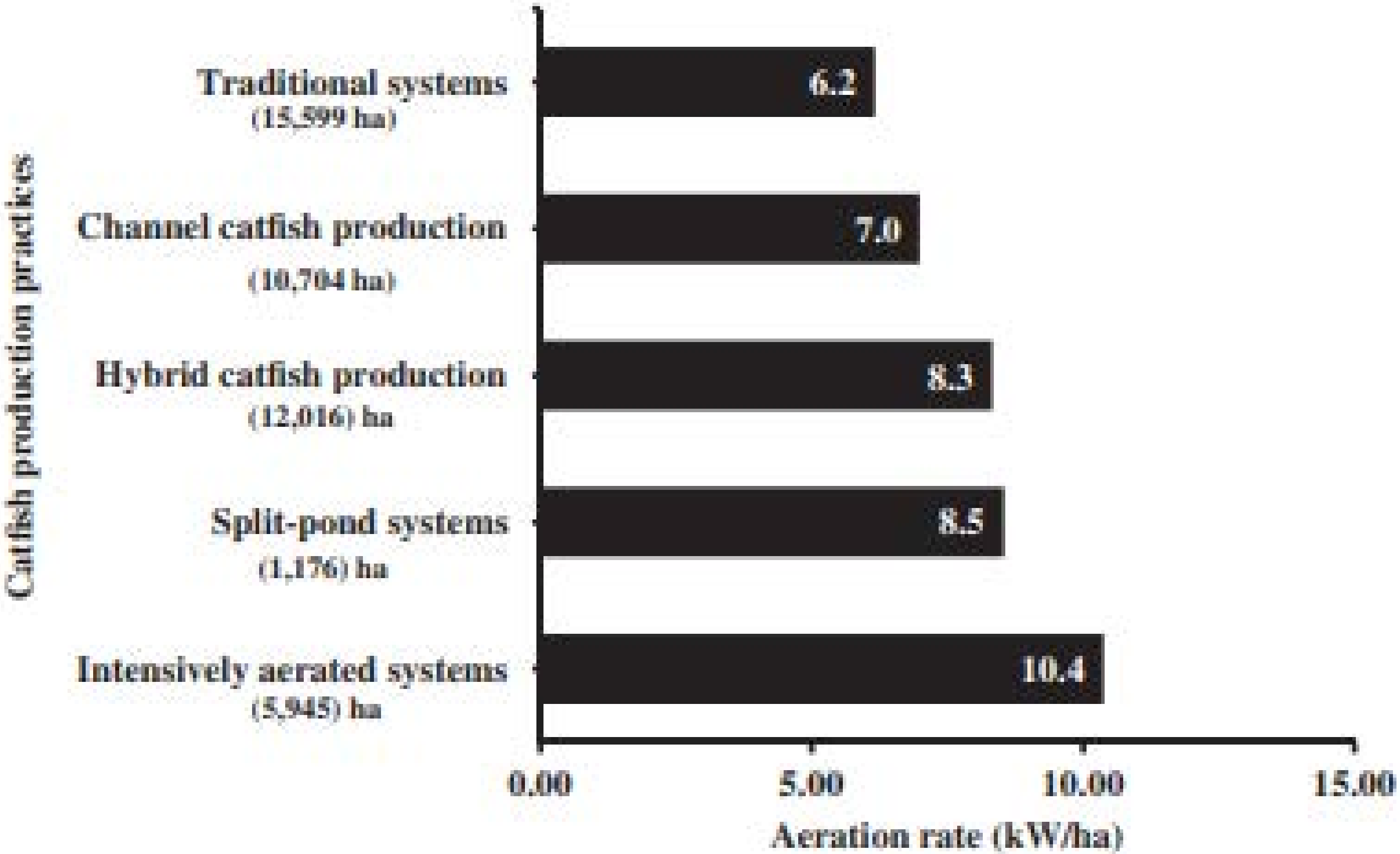
Increased aeration (electrical) energy usage (a, c)
Adaption of improved culture technology (b)
Automated oxygen monitors (d)
Hybrid catfish culture, Blue x Channel (e)
Catfish vaccination (f)



*Hegda, Kumar, Engle, et. al., Technological Progress in the U.S. Catfish Industry, World Aquaculture Society, 2021.

Increased Energy in Catfish Culture*

10 kW/ha = 5.4 hp/acre



*Hegda, Kumar, Engle, et. al., Technological Progress in the U.S. Catfish Industry, World Aquaculture Society, 2021.

Overview of Aquaculture Intensification *

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	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	200-300	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 advancements over 60 years; Fish/shellfish yields increased from 1,000 to 2,000 lbs/acre-year to 40,000 to 50,000 lbs/acre-year, year-round, climate-controlled, zero-discharge, recirculating aquaculture systems (RAS).

*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.

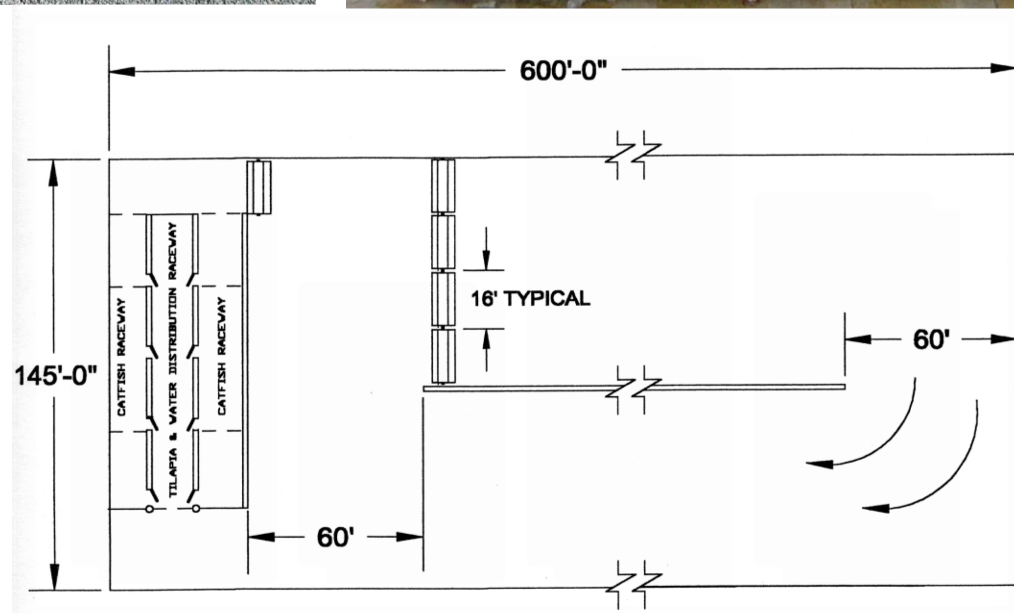
Advances in Aquaculture Technology

- Partitioned aquaculture (Clemson)
- Split-ponds (Mississippi)
- Intensive aeration (Mississippi)
- In-pond raceway (Auburn)
- Biofloc marine shrimp production (Clemson/MO)

Development of the Partitioned Aquaculture System at Clemson University; 1987-2008 – Enhanced Algal Treatment for Catfish Production

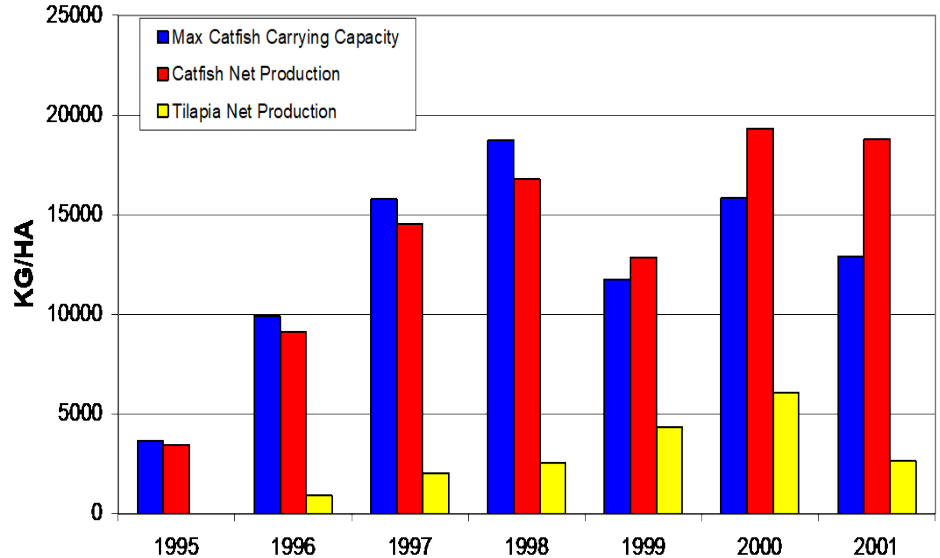
Converting pond fish culture to raceway culture

Two acres total with fish confined to 5% of area,



95% of pond area converted to high-rate algal pond for water treatment

Two-acre Partitioned Aquaculture System (PAS); Paddlewheels provide uniform water mixing promoting increased photosynthesis with fish in high-density raceways.



Clemson Two-Acre PAS
0.4 ft/sec water velocity

Catfish Yields in PAS ~18,000 lbs/acre
Tilapia co-culture for management of algae in a "High-Rate Pond," adapted for fish production

Lessons from University of California-Berkley, W.J. Oswald,1979

“Paddle-wheel Mixed High-rate Ponds for Wastewater Treatment”

4-5X increase in algal productivity in high-rate ponds
Algal harvesting costly; discharge land applied
Algal species stability issues (Bluegreen dominance)

Algal Control using Tilapia Filter-Feeding
Green (left) with tilapia, Bluegreen (right) without Tilapia

Tilapia filter-feeding biomass ~ 25% of target catfish biomass

Catfish Culture in Raceways

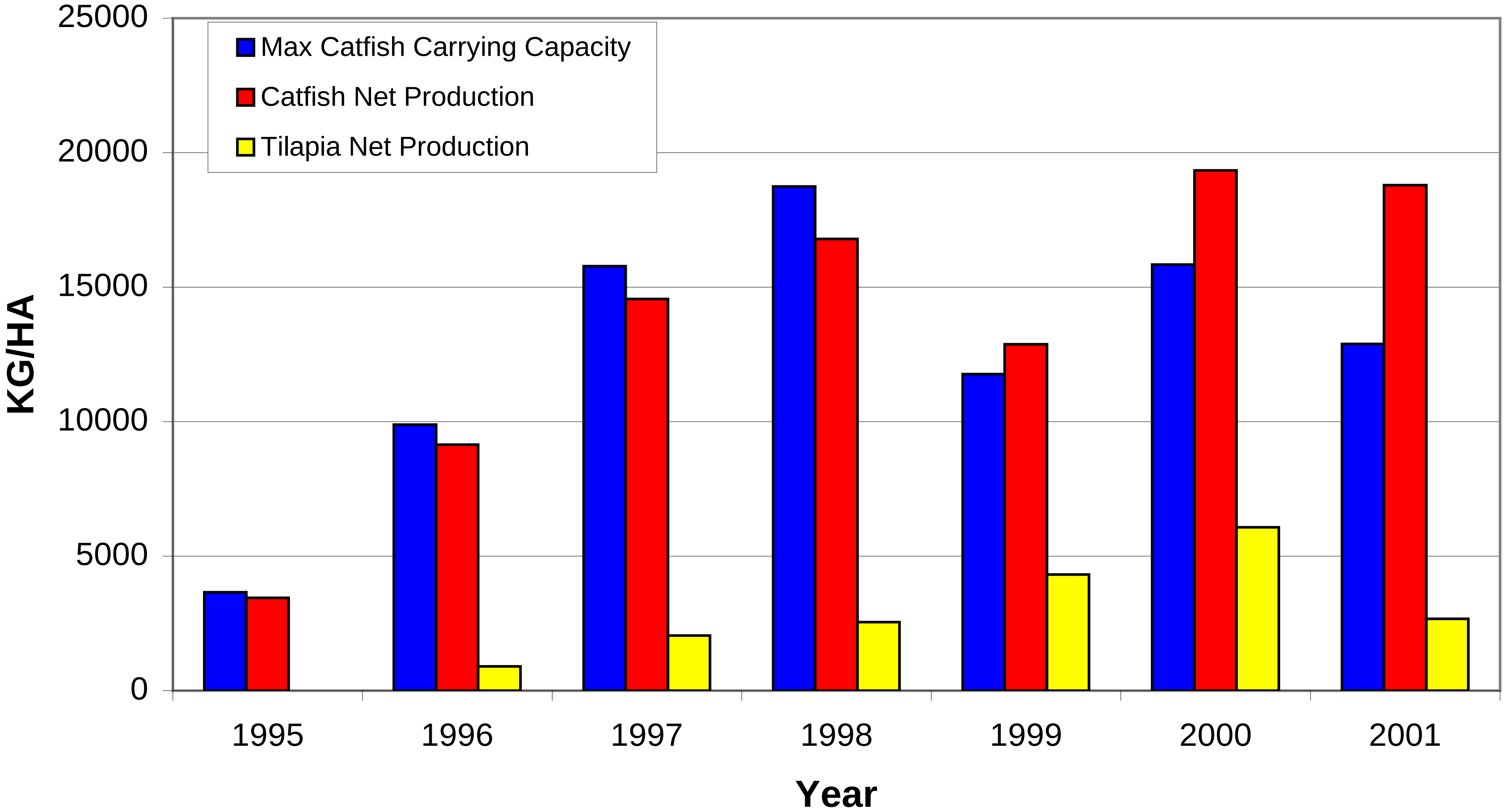
Bird predation eliminated

Improved feed conversion

1.5/1 vs 2.2/1

Ease of harvest/fish treatment

Catfish Production 1995 to 2001



Minimum Tilapia biomass at 25% of catfish yield

Tilapia must overwinter indoors in SC and MS

4-5 fold increase in photosynthesis, = 4-5 fold increase in fish production

18,000 lb/acre fish production in high-rate algal ponds

2014 & 2015 at Stoneville MS

Comparisons of Split-Ponds (SP) and Intensive Ponds (IP) at MS-State Delta Branch Experiment Station vs. Conventional Ponds (CP) and Partitioned Aquaculture Systems (PAS) for production of hybrid catfish (*Ictalurus punctatus* x *I. furcatus)*

Early Aquaculture Used Stillwater (wind aerated) Pond Production

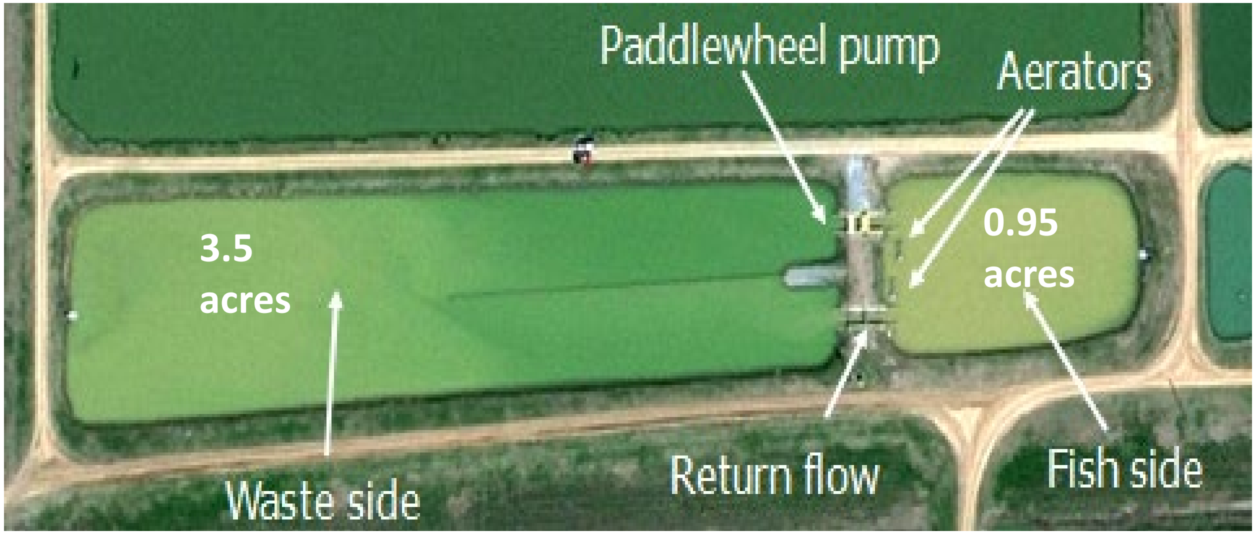
At average wind of 5 m/s, Oxygen transfer = 45 lb/acre-day

Fish oxygen demand = 15-30 lbs/acre-day at **1,000 to 2,000 lbs/acre**

Feed limited to 20-40 lbs/ac-day

Conventional aquaculture ponds, added 1-2 hp/acre aeration

2 hp/acre = 96 lbs O_2/ac-day
5,600 lbs/acre production
Algal production = 2-3 g C/m2-day,
Feed limited to 100 lb/acre-day

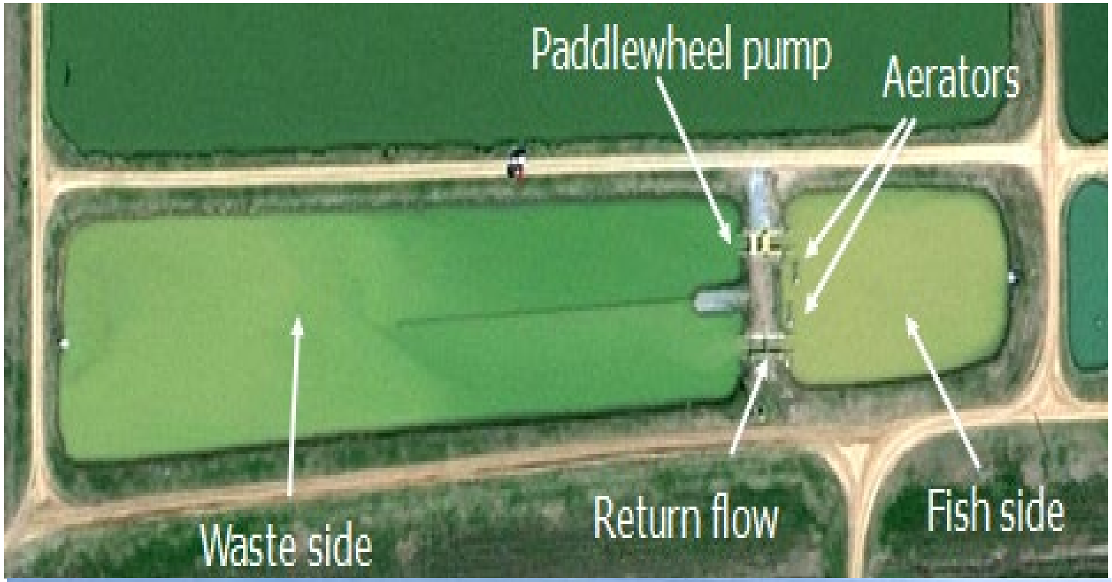


MS Split-Pond ; 2014 (4.5 acres)

1995-2008 Clemson PAS (0.05-2.0 acres)

2014 MS Intensive Pond (2.0 acres)

Split-ponds at Warmwater Aquaculture Center, Stoneville Mississippi

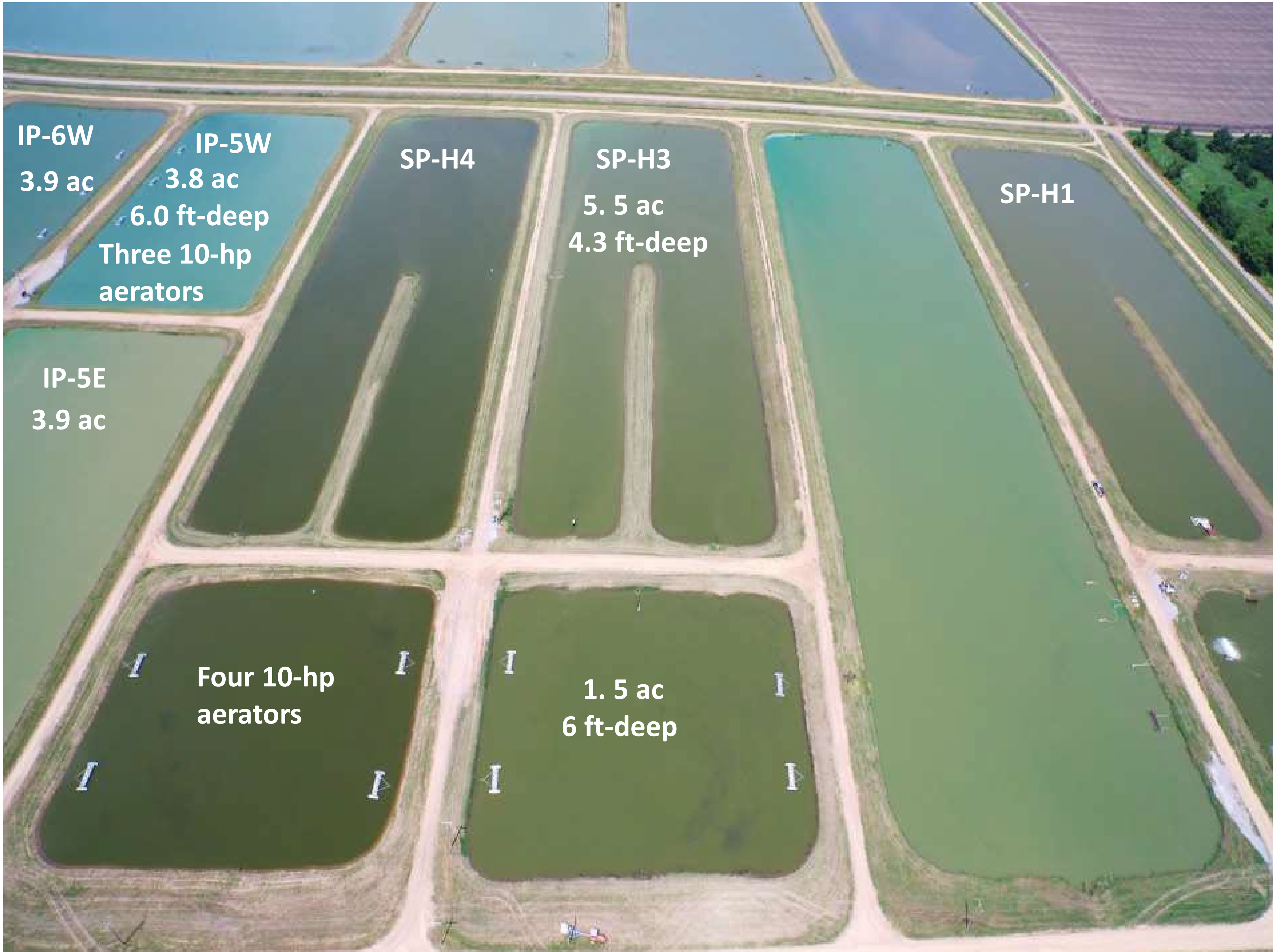


Lower-cost version of the PAS, the split-pond, at Mississippi demonstrates catfish production at 12,000 to 17,000 lbs/acre

Production in 5.0-7.0 acre split-ponds divided into water treatment and fish culture, fish confined to 25% of pond area

Paddlewheel Moving Water in Split-Pond at NWAC in MS

MS Split Ponds, Intensive Ponds and Conventional Ponds



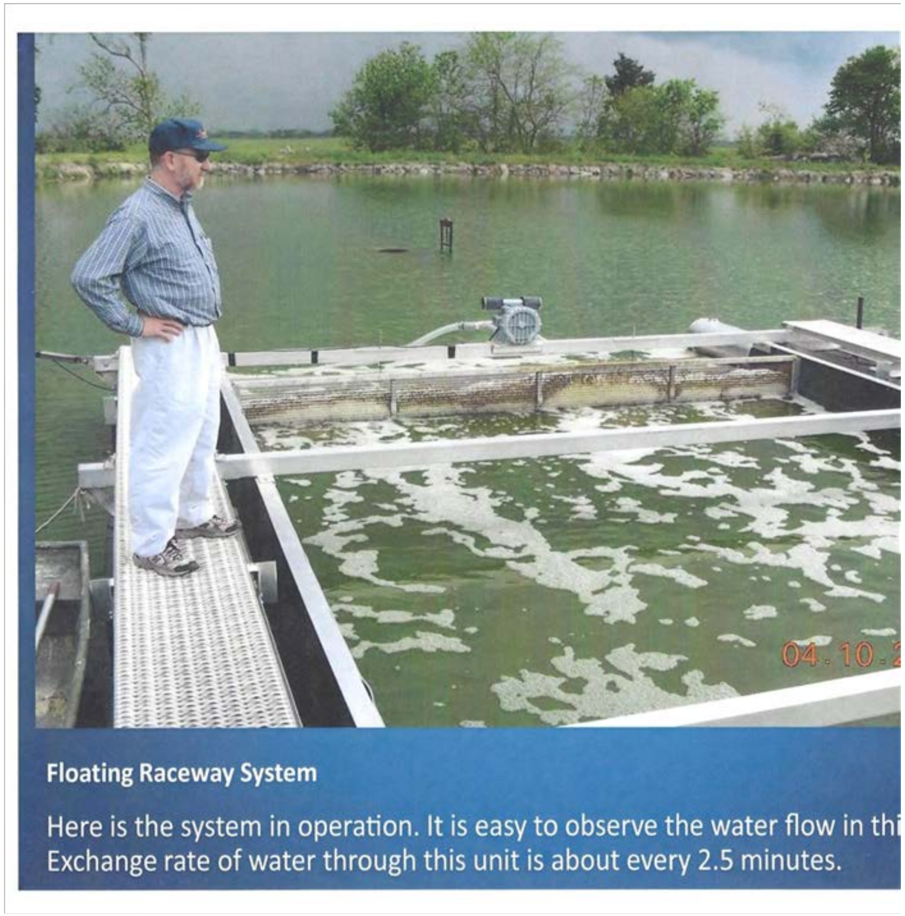
Enhanced Photosynthetic Catfish Production in Intensively Aerated Ponds

Intensively aerated ponds at NWAC/MS demonstrated 7,000–17,000 lb/acre-yr production in 1.0-4.0-acre ponds with fish confined to 100% of pond area

Enhanced Photosynthetic Catfish Production; In-Pond Fixed Raceways

In-pond raceways at Auburn University demonstrated maximum production of 16,000 lb/acre in 6.0-acre pond. Fish confined to 2.0% of pond area

Auburn In-pond Floating Raceways



Adaption of in-pond raceways limited by expense of technique

Fish Culture Footprint, Aeration Energy, and Yield of Enhanced Catfish Production

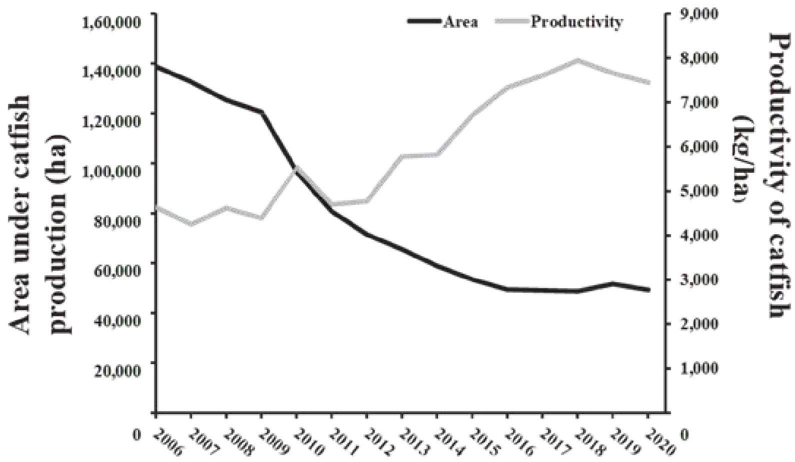
System	Fish Culture	Typical Acres	Aeration energy hp/ac	Ave yield lb/ac
PAS	5%	2.0	6.0	17,000-18,000
SP	20%	7-10	6-10	13,000-17,000
IP	100%	5 -7	6-10	7,000-17,000
IPR	2%	6	3.0	13,400
CP	100%	5-10	3.3	4,000-5,000

Maximum production similar in PAS, SP and IP

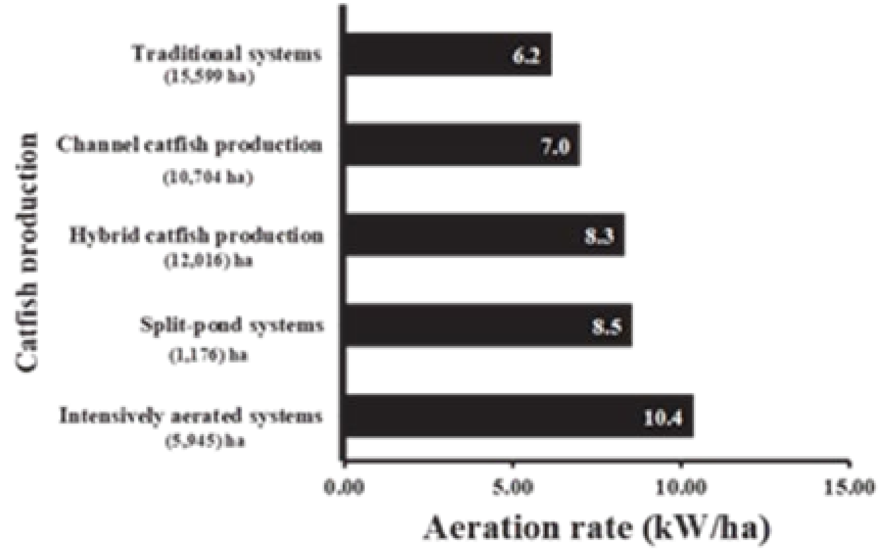
Production in IP more variable than in PAS and SP

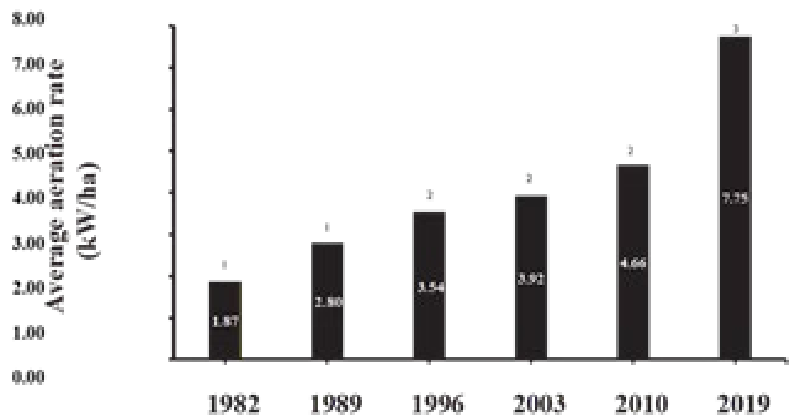
SP/IP lowest cost. PAS and IPR most expensive

Catfish Industry Intensification; Area and Energy Usage



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





Total catfish industry culture area decreasing, (60% over 14 yrs) productivity increasing (160% over 14 yrs). Pond aeration increased to 5.6 hp/acre in IP vs 3.3 hp/acre for CP

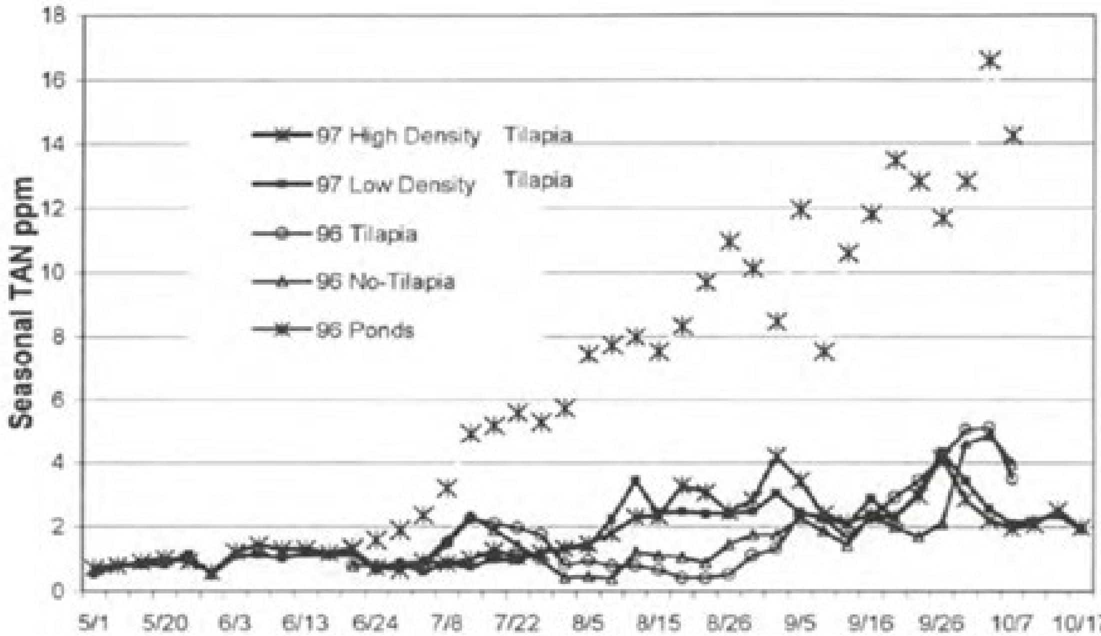
Advantages of Aquaculture Intensification

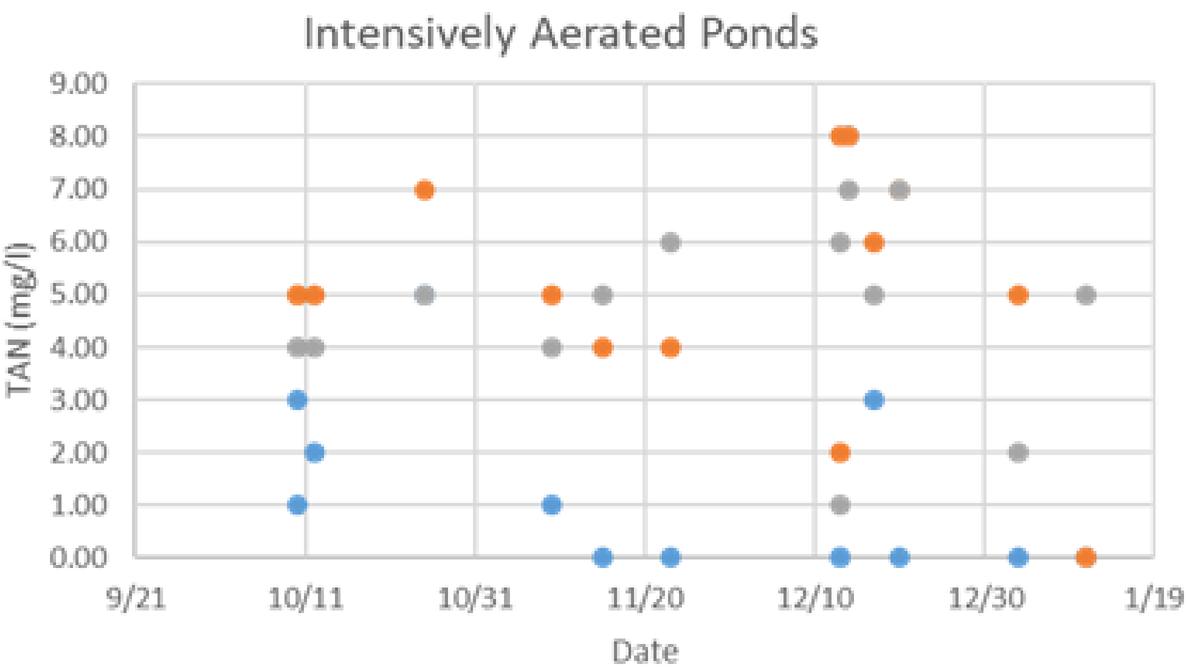
Increased efficiency of water, land and equipment/lb-production
Reduced cost/lb-production
Reduced labor needs/automation possible
Reduced fish predation
Improved fish health management and feed conversion

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 Control in Catfish Production Systems





Ammonia nitrogen levels in PAS and SP typically < 4.0 mg/l: Elevated levels of nitrogen and ammonia (> 4.0 mg/l) observed in conventional ponds and intensely aerated ponds

Marine Shrimp Production

University of Missouri Zero-Discharge Marine Shrimp Production

Biofloc expands production to 40,000 lb/acre

High levels of microbial solids (250-300 mg/l) within culture water

Types of Biofloc Water Treatment

Autotrophic Nitrification (Slow growth, low sludge production)

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

Heterotrophic Bacteria (Rapid growth, requires carbohydrate)

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

Photosynthetic System (Algal) With Bioprocessing of Solids

Feed

Nitrogen Waste

Algal Biomass 300 lb max feed/ac-day

Food and Feed

Bioenergy

Brine shrimp

Slow Release Biofertilizer

Autotrophic System (Nitrifying/Denitrifying Bacteria) 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

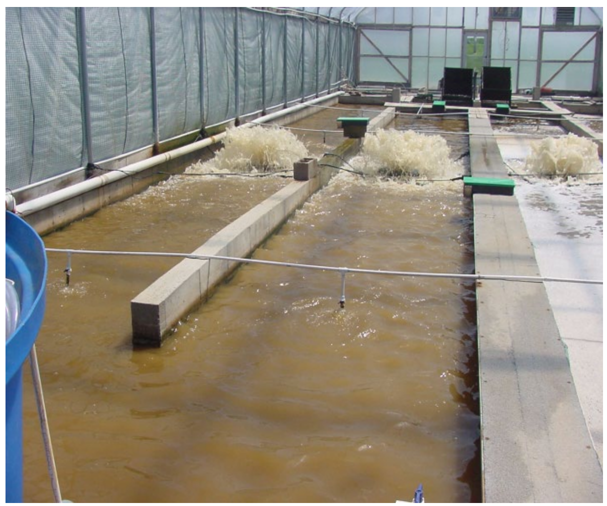
Heterotrophic System (Bacteria) With Bioprocessing of Solids

Feed

Carbohydrate Addition = 85% of feed

Nitrogen Waste

Bacterial Biomass Feed C/N = 12-15/1



Biofloc

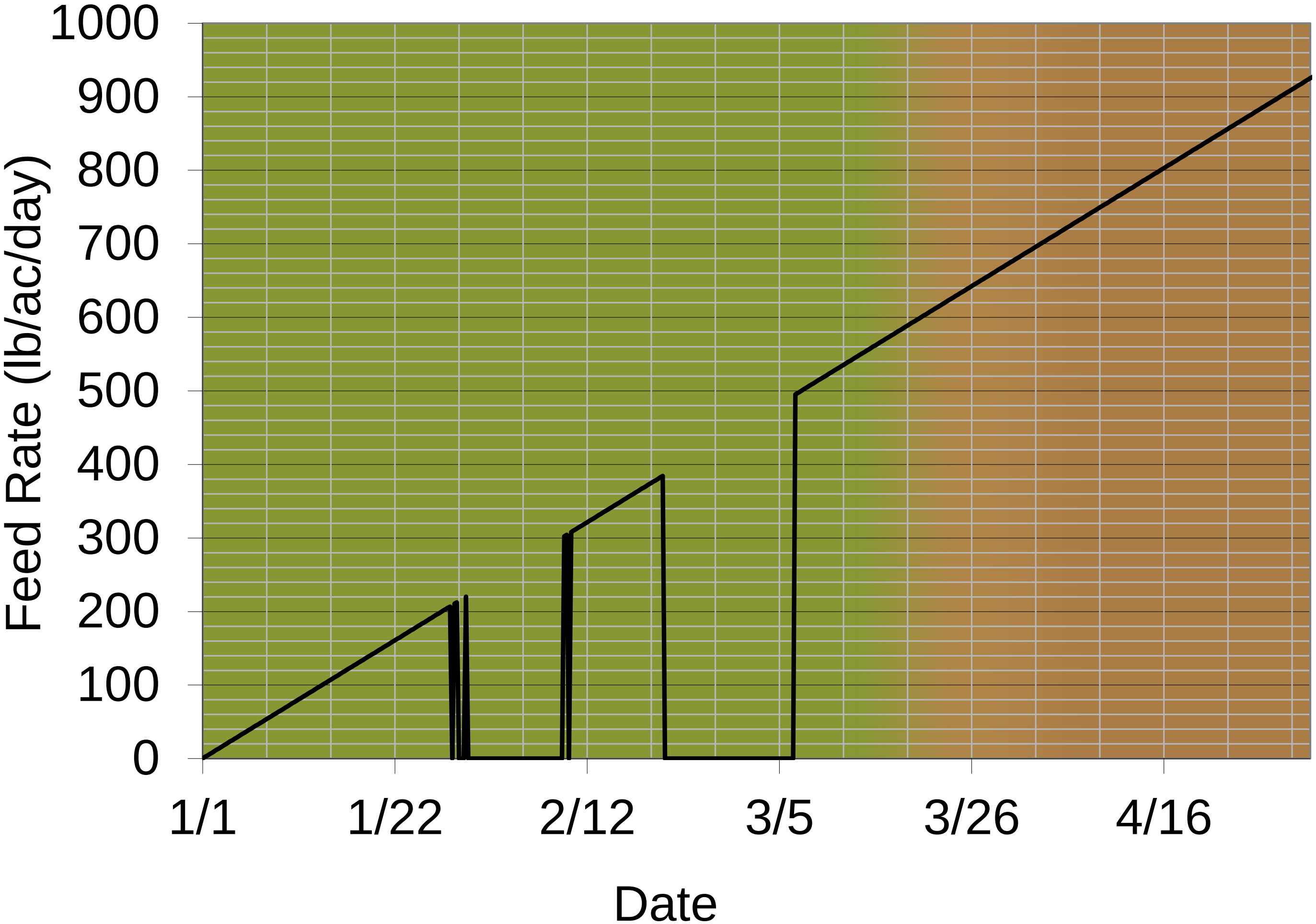
Food and Feed

Brine shrimp

Bioenergy

Slow Release Biofertilizer

Biofloc = Special case of suspended-cell microbial culture



Algal vs bacterial water treatment algal up to 250-300 lb-feed/ac-d nitrifying at C/N of 9/1, heterotrophic at C/N of 12-15/1

Water color in shrimp culture as feed passes 300 lb/acre; algal culture replaced by bacterial culture

Catfish and Shrimp Culture in Ponds in Warm Climates

Intensive aeration allowing catfish to expand from 2,000 to 10,000 lbs/acre in captive water

Intensive aeration with water discharge allowing shrimp to expand from 1,000 to 10,000 lbs/acre

The Drive to Zero-Discharge Aquaculture

Animal agriculture recovers only a small fraction of feed-N

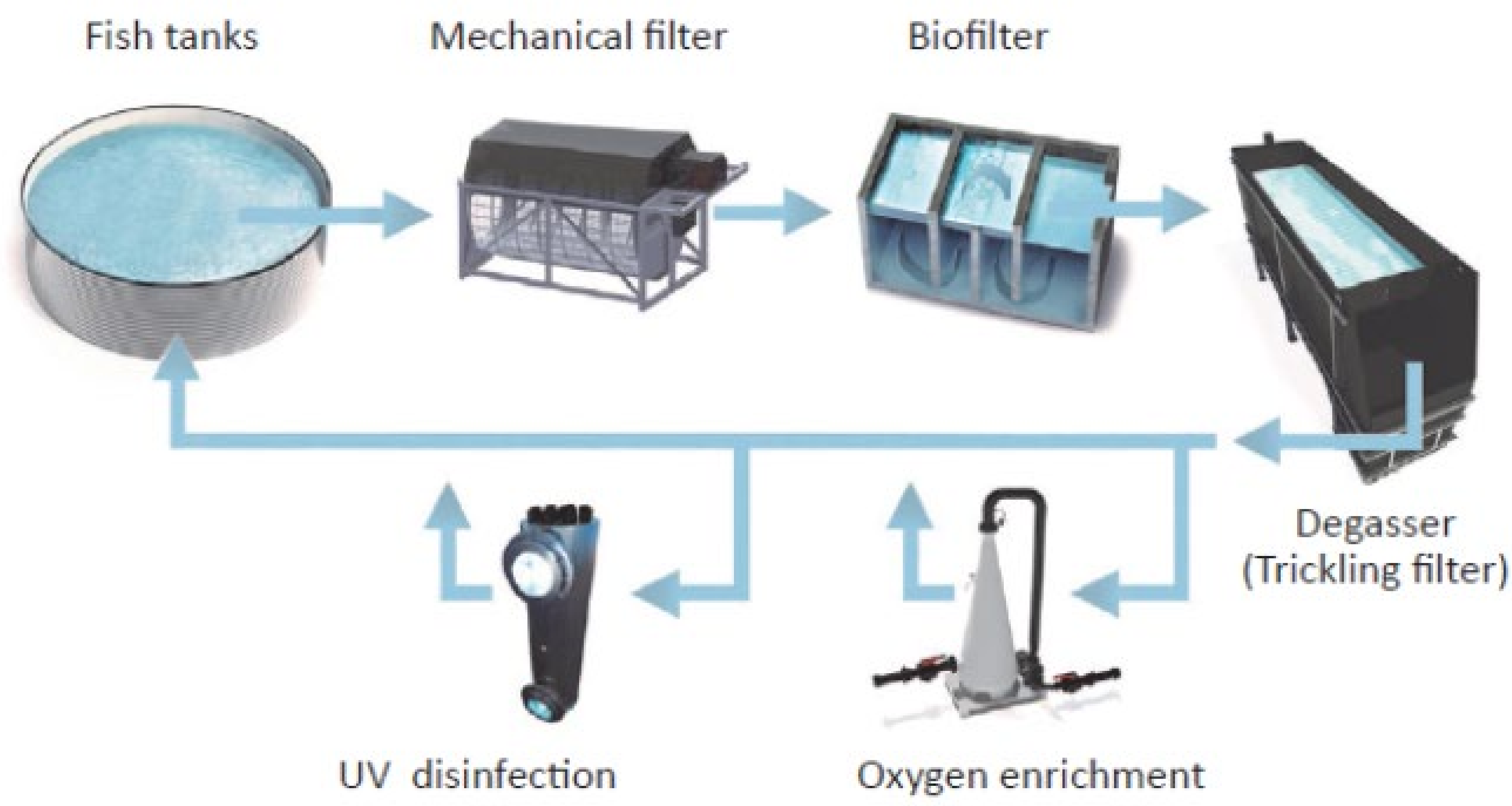
Soy, corn & fish-meal nitrogen inputs

12 - 21% protein nitrogen converted to fish or shrimp

79 - 88% nitrogen discharged as pollutant

Recirculating Aquaculture Systems (RAS)

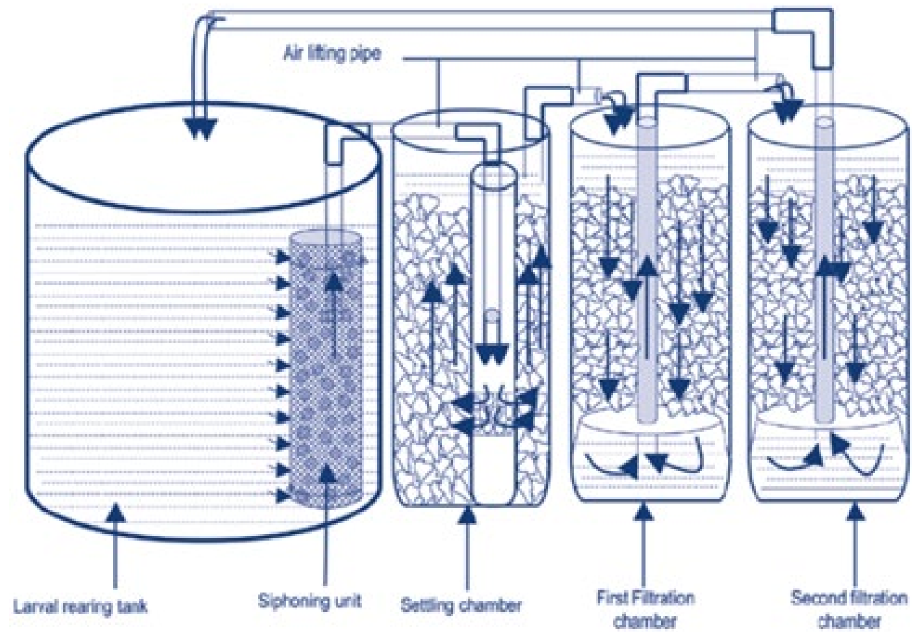
Water Treatment Components



In cooler zones, or where water discharge is restricted, RAS units provide continuous water treatment, using mechanical filtration, microbial treatment and aeration/stripping, oxygen enrichment and UV disinfection

Clean-water RAS uses fixed-film biofilters to treat ammonia

Aquaculture biofilter with plastic media for bacterial support



Aquaculture biofilter using wood chips in Bangladesh

RAS typically used for cold-water, clean-water species

Hybrid Stripped Bass Production at Kent SeaTech Corporation in California

Recirculating System for Largemouth Bass in Missouri

4,200 gal grow-out tanks, 1,500-gallon biofilters with plastic media

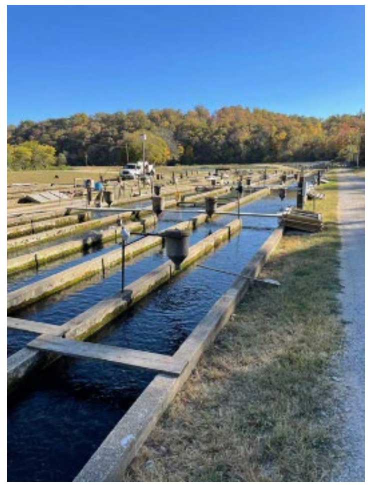
Capital costs ~ $5.00/gallon, Fish selling price ~ $6.00/lb

Carrying capacity; 12,000 lbs largemouth bass

GROWING MISSOURI'S AQUACULTURE INDUSTRY*

*FUNDED BY MISSOURI AGRICULTURE AND SMALL BUSINESS DEVELOPMENT AUTHORITY (MASBD 2022-2023)

Extension
University of Missouri



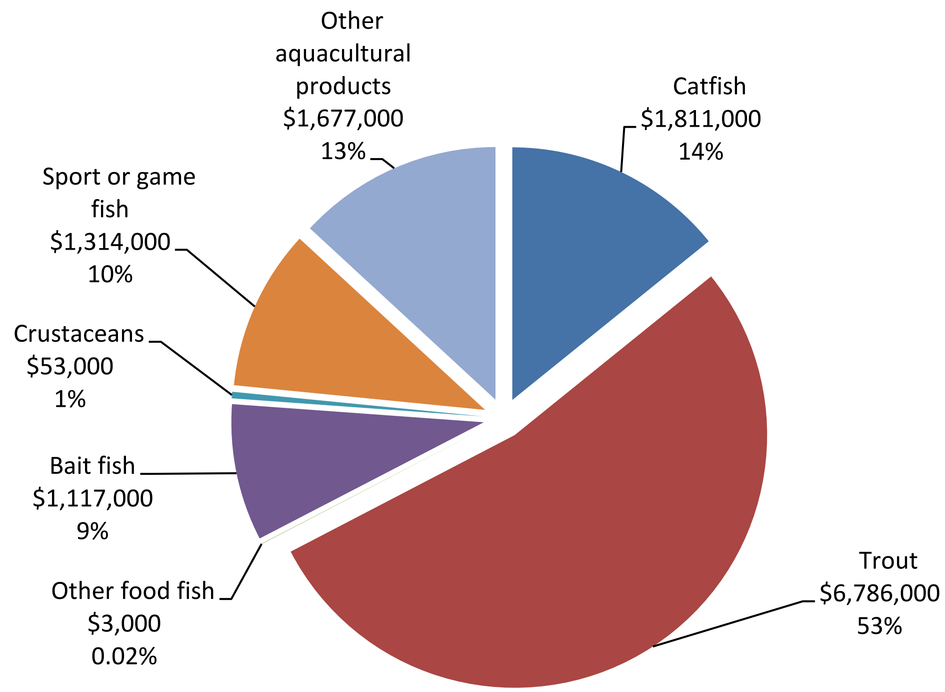
Joe Horner, Ryan Milhollin, Alice Roach, Mallory Rahe, David Brune, Robert Pierce, Drew Kientzy, Laura Gordon

Missouri Farmers Ask,
Can Aquaculture Expand Farm Production and Income?

Marine Shrimp and Stripped Bass

Aquaculture Value in Missouri

- Value of production ~ $13.3 million in 2018
- Channel catfish and rainbow trout 2/3 value of production in 2018



Missouri Aquaculture Market Value
USDA Census of Aquaculture 2018

Missouri business models/enterprise budgets provide options using ponds or RAS

Model	Culture System	Annual Production (Pounds)	Primary Market Channel	Capital Investment (Dollars)	Annual Sales (Dollars)
Catfish	Pond	76,500	Recreational stocking	438,050	382,500
Bluegill	Pond	54,600	Recreational stocking	438,050	819,000
Bass	Pond	50,400	Recreational stocking	438,050	315,000
Grass Carp	Pond	25,650	Recreational stocking	438,050	149,625
Catfish	RAS	63,384	Food fish (live)	360,353	273,537
Bass	RAS	40,102	Food fish (live)	360,353	240,611
Shrimp	RAS	15,513	Food fish (live)	360,353	310,262
Tilapia	RAS	142,467	Food fish (live)	360,353	356,168

Bluegill production in ponds for stocking provide highest income/investment ratio

Products from MASBD Project

The project entitled, “Next Generation Aquaculture in Missouri” (funded by the Missouri Agriculture and Small Business Development Authority serves as template for existing project. The MASBDA project led to four publications accessible at: https://extension.missouri.edu/programs/aquaculture-extension

- Growing Missouri’s Aquaculture Industry: Trends and Outlook
- Growing Missouri’s Aquaculture Industry: Needs Assessment.
- Growing Missouri’s Aquaculture Industry: Marketing Study
- Growing Missouri’s Aquaculture Industry: Business Models

Trends and outlooks summarized global aquaculture industry trends and offers further detail about channel catfish and rainbow trout — the major fish species grown by Missouri aquaculture producers.

Missouri’s aquaculture industry consists of small but diverse businesses representing 17 counties. The average is a small business with seven employees in business for 39 years. They primarily use ponds or flow-through raceways producing 46 different species. Bluegill and largemouth bass were most common, contributed 21% -25% of business sales.

The market survey showed Missouri captured 1% of U.S. aquaculture sales. Missouri’s industry exhibited 3% sales growth from 2013 to 2018. Missouri generated 3% of all U.S. baitfish sales. Food fish contributed 66% of state’s aquaculture sales. Food fish sales increased 36% from 2013 to 2018

The business models reports on issues to consider before building an aquaculture operation. Missouri has a diverse aquaculture industry; varied topography and groundwater availability have guided existing operation locations. Mild winters in the southeast region of the state provide a more favorable production season than other Missouri areas

ADVANCING AQUACULTURE IN THE MIDWESTERN REGION
(NCRAC Funded Project - $177,158, 2024-2025)

Extension
University of Missouri

PI: David Brune Professor, University of Missouri

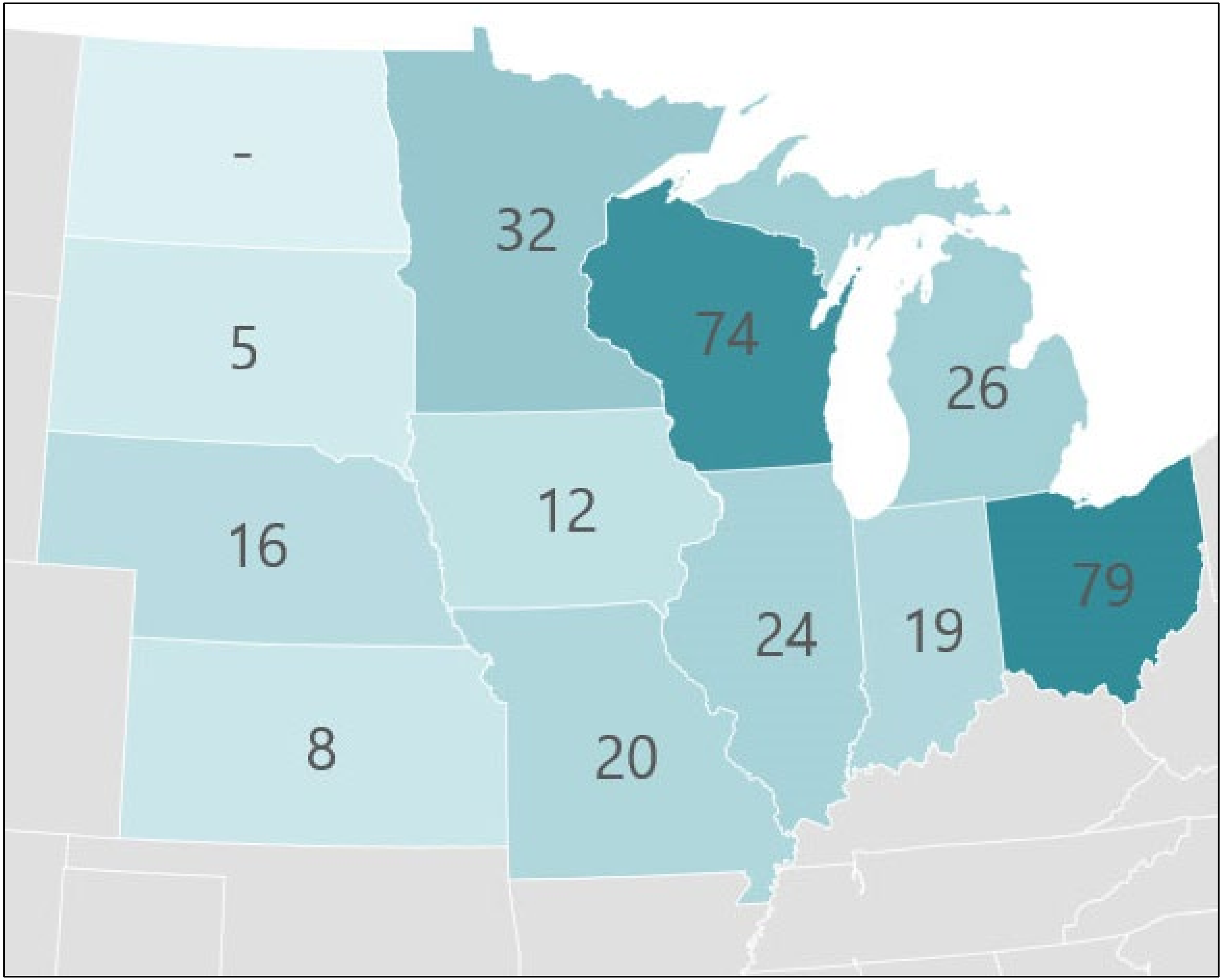
Co-PI(s): Paul Brown and Kwamena Quagrainie Purdue University, Dong Fang Deng, University of Wisconsin, Simone Valle de Souza, Michigan State University, Ryan Milhollin, Mallory Rahe, Adauto Roacha, and Robert Pierce, University of Missouri.

Justification

For Midwestern aquaculture to grow, we must understand how to expand into new markets and how to design efficient and cost-effective systems capable of maximizing business performance and economic success.

Project Objectives

- Objective 1 – Summarize trends and outlook for U.S. and Midwestern aquaculture.
- Objective 2 – Conduct site visits supporting a needs assessment of existing Midwestern aquaculture producers.
- Objective 3 – Conduct consumer survey via distributed questionnaires to determines north central regional aquaculture needs and potentials.
- Objective 4 – Provide business model/enterprise budgets for most promising Midwestern aquaculture species and cultural operations.
- Objective 5 – Develop aquaculture educational materials, provide training sessions, webpages and symposium presentations.



Aquaculture Farms in North Central Region, 2023
Wisconsin and Ohio largest number of farms

	Food fish	Sport fish	Bait fish	Ornamental fish	Miscellaneous aquaculture
Illinois	19	16	6	3	0
Indiana	6	9	1	3	1
Iowa	6	4	6	1	5
Kansas	4	4	3	0	0
Michigan	20	12	4	4	3
Minnesota	12	7	9	1	1
Missouri	17	8	11	5	4
Nebraska	18	7	4	3	2
North Dakota	0	0	0	0	0
Ohio	33	29	14	13	6
South Dakota	2	1	2	0	0
Wisconsin	45	16	7	3	3
Total NCR farms	182	116	67	36	25
Total U.S. farms	1,071	264	168	263	189
% NCR of U.S farms	17%	44%	40%	14%	13%

Aquaculture Number of Farms by Product Type Sold, 2018

NCR significant sport fish and bait fish production

Fish Species *(Category)*	**NCR Farms**	**U.S. Farms**	**% of U.S.**
Bass, hybrid striped *(food fish)*	17	62	27.4%
Carp *(food fish)*	34	100	34.0%
Yellow perch *(food fish)*	52	65	80.0%
Tilapia (food fish)	28	137	20.4%
Trout (food fish)	78	334	23.4%
Bass, largemouth (sport fish)	73	195	37.4%
Crappie (sport fish)	36	65	55.4%
Sunfish (sport fish)	70	171	40.9%
Walleye (sport fish)	38	42	90.5%
Fathead minnows (baitfish)	55	114	48.2%
Goldfish (baitfish)	9	35	25.7%
Golden shiners (baitfish)	23	67	34.3%
Goldfish (ornamental)	13	54	24.1%
Koi (ornamental)	31	149	20.8%

Aquaculture Farms by Species, 2018

NCR Dominates in Yellow Perch and Walleye Production

	Total		Food fish		Sport fish		Bait fish	
Geographic Area	Sales ($1,000)	5-year change (%)	Sales ($1,000)	5-year change (%)	Sales ($1,000)	5-year change (%)	Sales ($1,000)	**5-yea chang (%)**
Illinois	4,080	43%	-	-	2,861	56%	-	
Indiana	3,403	56%	-	-	-		-	
Iowa	3,828	36%	-	-	$115	-38%	124	
Kansas	1,003	75%	745	-	-		-	
Michigan	3,090	102%	1,843	56%	814	175%	267	
Minnesota	3,971	-29%	-	-	1,700	-	1,583	**-34**
Missouri	7,672	3%	5,096	36%	570	-	982	**3**
Nebraska	2,761	15%	2,343	3%	319	239%	-	
North Dakota	-	-	-	-	-		-	
Ohio	6,658	40%	2,677	89%	1,543	57%	2,131	**27**
South Dakota	-	-	-	-	-		-	
Wisconsin	6,249	18%	2,260	-6%	-		2,038	**32**
Total NCR	42,715	16%	14,964	8%	7,922	126%	7,125	**8**
United States	1,515,680	10%	715,978	-2%	39,350	65%	32,778	**12**
% NCR of U.S.	**2.8%**		**2.1%**		**20.1%**		**21.7%**	

Value of Aquaculture Products Sold, 2018

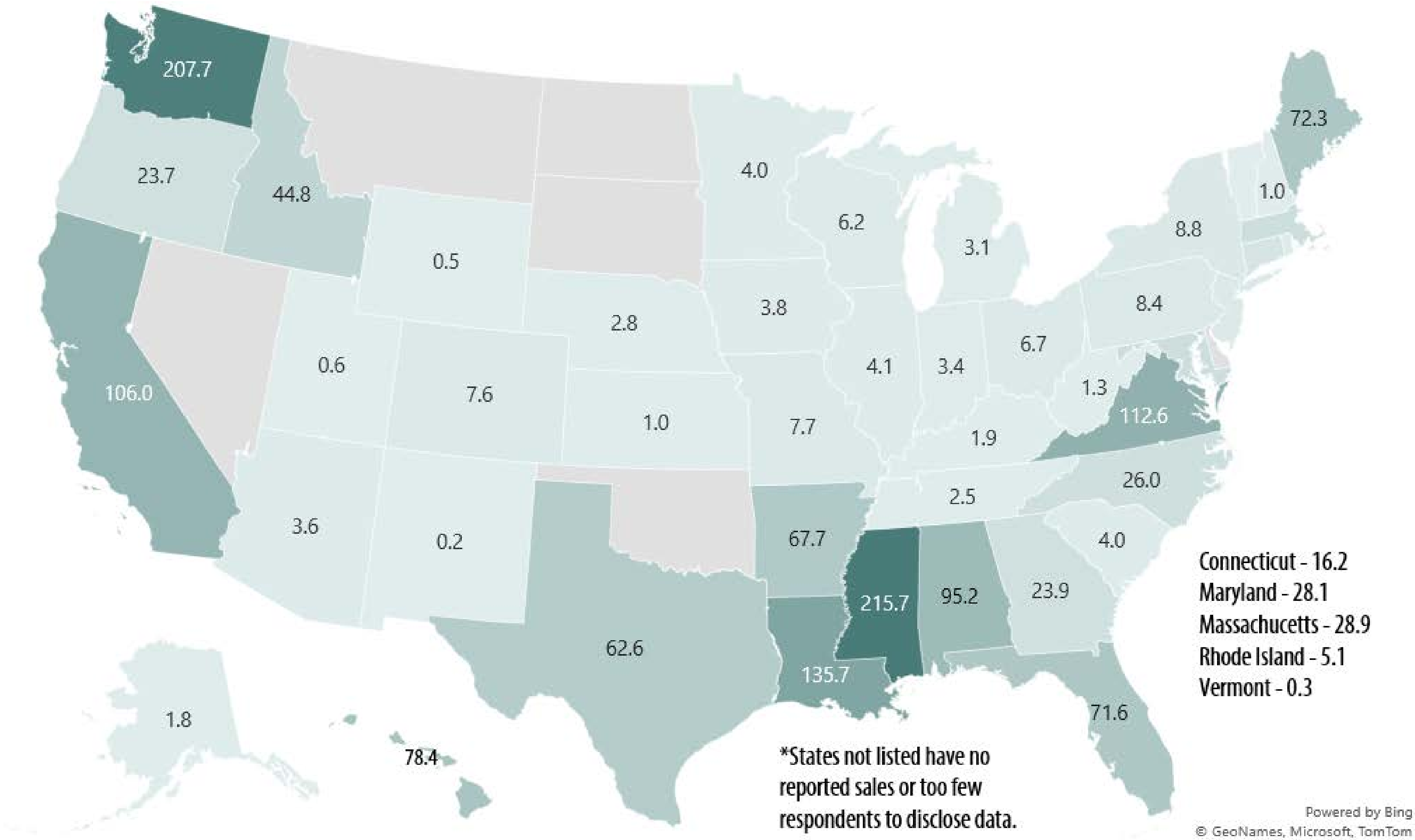
Missouri, Ohio, Wisconsin dominate in value

Geographic Area	Ponds	Tanks	Aquaponic systems	Recirculating systems	Raceway	Cage or pens
Illinois	34	6		1	7	8
Indiana	18	4		5	4	
Iowa	14	5		7	6	39
Kansas	10	2		2	3	
Michigan	32	12		5	13	4
Minnesota	34	23		8	9	
Missouri	26	7		6	13	
Nebraska	19	7		3	11	
North Dakota	3	3			1	
Ohio	56	15	3	27	11	
South Dakota	8	7			4	4
Wisconsin	63	17	9	14	34	
Total farms	317	108	12	78	116	55

Methods Used in Aquaculture Production, 2018

Ponds dominate production

Aquaculture in the U.S.: Major Production Areas



U.S. Aquaculture Sales, in Million Dollars: USDA 2018

Mississippi (catfish) and Washington (mollusks) dominate sales

Aquaculture Site Visits in North Central Region

Hanilu Farms (Barramundi), Cutler Indiana

Tippco Fish Inc (Tilapia), Romney Indiana

Freshwater Farms of Ohio (Trout), Urbana Ohio

Harrietta Hills Trout Farm (Trout), Harrietta Michigan

Millcreek Perch Farm (Yellow Perch), Maryville Ohio

Ozark Fisheries (Ornamental Fish), Stoutland Missouri

Gollon Brothers International, Ltd (Bait), Stevens Point Wisconsin

Superior Raceway Systems, Stevens Point Wisconsin

RDM Aquaculture LLC (Shrimp), Fowler Indiana

Rushing Waters Fisheries (Trout), Palmyra Wisconsin

Site Visits to Date

Ozark Fisheries in Missouri. 300 acres of pond-reared goldfish. Selling to wholesale markets and direct on-line consumer sales

RDM Shrimp in Indiana. Pacific White Shrimp in biofloc RAS tanks. Selling seed shrimp to growers and heads-on shrimp direct to consumers

Hanilu Grow-out tanks

Hanilu Farms in Indiana. Barramundi in 1,600 gallons of RAS tanks. Selling live fish to wholesale market

Freshwater Farms Smoked Trout and Trout Filets

Freshwater Farms of Ohio. Trout production in RAS and ponds. Selling smoked trout and processed fish-fillets direct to consumers

Aerial View of Big House Fish Farm

Big House Fish Farm of Illinois. 10 acres of pond reared large mouth bass. Selling to wholesale live markets.

Superior Aquaculture selling in-pond raceways to companies in U.S., Africa, and Canada Raceways containing 48,000 gallons of water. Water flow provided via air-lift pumps powered by regenerative blowers. Raceways typically placed in 2-to-4-acre ponds.

Superior Aquaculture LLC in Wisconsin, Selling In-Pond Raceways

MISSOURI BUSINESS MODELS RAS SHRIMP (food)

- 3-month production cycle
- Direct consumer sales

	Total ($)	$ Per Lb. Sold
Net revenue	282,338	18.20
Total costs	234,972	15.15
Net return to operation	47,366	3.05
		+18% BE

Shrimp RAS Budget

Item	Unit	Value
Shrimp sales price	Dollars per pound	$20
Floating feed (46% protein)	Dollars per ton	$2,400
Shrimp larvae	Dollars per larvae	$0.10
Veterinary health	Percent of sales	2%
Stocking capacity	Pounds per gallon	0.07
Shrimp finish weight	Grams	22.00
Survival rate	Percent	75%
Feed conversion ratio	Feed per pound gain	1.40
Larvae weight	Pounds	1.30
Turns per year	Turns	3.50
Hired labor	Hours	1,750
Average delivery distance	Miles (round trip)	400
Average delivery weight	Pounds per delivery	500

MISSOURI BUSINESS MODELS RAS TILAPIA (food)

- 8-month production cycle
- Live-food fish market

	Total ($)	$ Per Lb. Sold
Net revenue	292,057	2.05
Total costs	296,294	2.08
Net return to operation	**-(4,236)**	**-(0.03)**

Tilapia RAS Budget

Item	Unit	Value
Tilapia sales price	Dollars per pound	$2.50
Floating feed (45% protein)	Dollars per ton	$725
Tilapia fingerlings	Dollars per fish	$0.20
Veterinary health	Percent of sales	2%
Stocking capacity	Pounds per gallon	1.25
Tilapia finish weight	Grams	1.40
Survival rate	Percent	90%
Feed conversion ratio	Feed per pound gain	1.50
Fingerling weight	Pounds	0.01
Turns per year	Turns	1.50
Hired labor	Hours	3,000
Average delivery distance	Miles (round trip)	400
Average delivery weight	Pounds per delivery	2,000

Planned business models/enterprise budgets

- Trout production in RAS and raceways.
- Baitfish in ponds.
- Yellow Perch in ponds and RAS.
- Salmon in RAS.
- Walleye in RAS for food and stocking.
- Largemouth Bass in ponds for stocking and food.
- Tilapia in RAS for food and stocking.
- Ornamental fish in ponds and RAS
- Aquaponics

2024/2025 OUTCOMES/BENEFITS

Midwestern aquaculture trends and outlook summary

Report documenting consumer demand/willingness to pay, and identification of buyers/preferences for a variety of aquaculture products

Aquaculture business models/enterprise budgets supporting cost-effective expansion of existing aquaculture operations and establishment of new enterprises.

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Evaluation of Prototype, Zero-Discharge, Temperature-Controlled, Recirculating Aquaculture System
Private Farm in Morgan County Missouri

Site Preparation in Morgan County, Missouri;
0.28 Acres; Cost = $3,500

Building Construction; Cost = \$120,000 + electrical (\$10,000) + site preparation (\$3,500), Total cost = \$133,500 or \$22.25/ft^2)

“Sukup” Building; 100 x 60 ft = 6,000 ft^2
Insulated walls and roof on 6-inch concrete pad

Prototype Raceways and Water Collection Sump

30-Mil HDPE Liner inserted into ¾ Inch plywood containment, providing 2,800 gallons; Liner cost = $700, plywood containment = $4,200 Total cost = $1.75/gallon

½-Inch welded PVC sheets inserted into ¾ inch plywood;
PVC liner cost = $1,000, plywood containment =$4,200 Total cost = $1.86/gallon

Commercially-available, glass-coated steel raceway, anchor-bolted to concrete; Cost = $24,380 for 8,600 gallons, Total cost = $2.83/gallon

Concrete-filled, prefabricated PVC (7,200 gallons)
PVC Forms (\$3,000) + concrete (\$2,000) + lumber (\$1,500)
Total cost = \$0.90/gallon

Water Supply
25-gpm well ($6,600) + plumbing ($4,000)



Supporting equipment; Rotary-compressor ($5,600), Oxygen-separator ($7,000), Bead-filter ($4,400), Blowers/Ozone-generator ($2,700), Machine room ($6,500)

Production Cost (Fish vs Shrimp) $/lb in Concrete-Filled PVC

Capital Costs ($/lb)	Bass	Shrimp (Auto)	Shrimp(Hetero)
Building	0.232	0.617	0.463
Heat Pump	0.111	0.296	0.222
Generator	0.035	0.093	0.069
Raceways	0.181	0.604	0.453
Filters	0.124	0.156	0.117
Aerators	0.082	0.272	0.204
Pumps	0.013	0.042	0.031
Total Capital	**0.778**	**2.080**	**1.557**
Steel tanks	+0.433	+1.796	+1.357
Operating Costs ($/lb)			
Feed	1.500	1.080	1.080
Sugar	0	0	1.032
Animals	0.784	2.428	2.428
Aeration KWH	0.213	0.760	0.570
H/C KWH	0.286	0.760	0.570
Labor	0.638	2.122	1.592
Total Operating	**3.421**	**7.150**	**7.272**
TOTAL COSTS	**$4.20/lb**	**$9.23/lb**	**$8.83/lb**

Aquaculture Production Costs; Pond vs RAS

Estimated Costs/Prices ($/lb) for Whole/Processed Pond and RAS Products

Type/Yield	Break-Even(whole)	Farm-gate (whole)	Wholesale (processed)	Retail (processed)
POND				
Catfish (32% fillet)	0.80-1.00/lb	0.85-1.25/lb	5.00-6.00/lb	8.0-11.00/lb
Shrimp (60% heads)	1.50-1.90/lb	2.00-3.00/lb	5.00-6.00/lb	6.00-11.00/lb
RAS				
Shrimp (60% heads)	8.00-9.00/lb			15.00-18.00/lb whole
Bass (32% fillet)	4.00-6.00/lb	5.00-6.00/lb	15.00-18.00/lb	20.00-28.00/lb

Recirculating System Production Costs, Marine shrimp = 8.00-9.00/lb, Bass = 4.00-6.00/lb

Typical Commodity Farm-Gate Price, Catfish = 1.25/lb, Bass = 6.00/lb, shrimp =3.00/lb

Recirculating System Costs = 1-6X commodity prices, 45-65% of niche market price

Break-even cost dependent on scale, species, productivity, RAS costs variable based on small sample size

Recirculating aquaculture production costs cannot compete with southern U.S. pond production costs or seafood commodity costs; RAS production cost = 4 to 6-fold over farm-gate or dock-side prices. However, retail seafood prices allow 10-20% profit margins

Summary

- Zero-discharge, controlled-climate, RAS production costs range from $4.20/lb (fish) to $9.23/lb (marine shrimp)
- Profitability of zero-discharge RAS will require retail sales
- Growers must bear costs of seafood holding, processing, transportation, packaging, and advertising/marketing to sell product directly to consumers
- Begin small, consider markets before addressing technology and investment issues; Which marketable species? What product to provide (whole or processed)? Where to sell?

Life Cycle Analysis of Prototype, Zero-Discharge Controlled Climate RAS

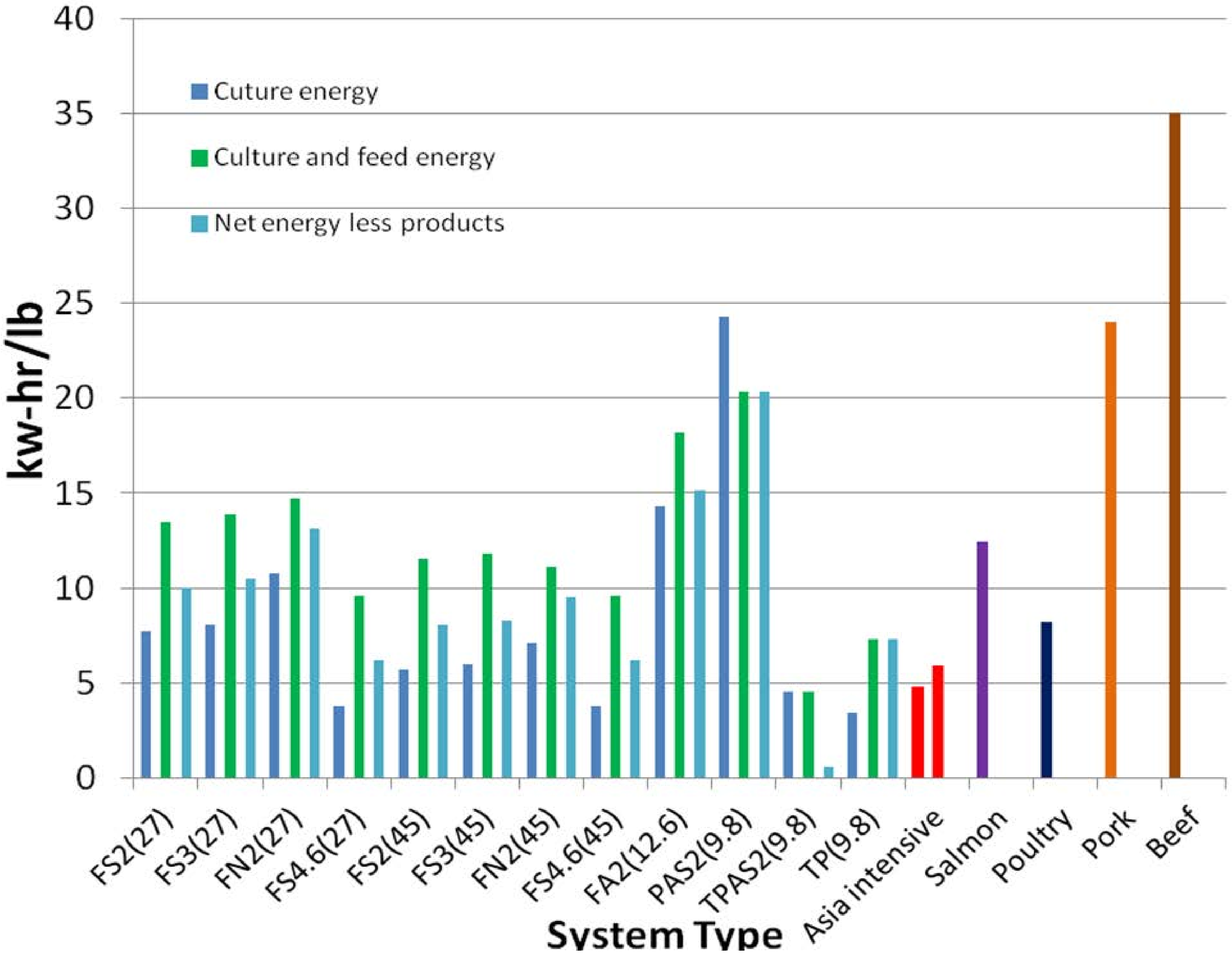
42,000 lbs/yr of striped bass within 6,000 ft^2 climate-controlled insulted metal building
Energy Consumption; 3.28 kw-h/kg for aeration, 6.3 kw-hr/kg for climate control, 2.1 kw-hr/kg for pumping, and 2.1 kw-hr as embodied feed energy; Totaling of 13.7 kw-h/kg live wt or 27.6 kw-hr/kg processed weight
Water Usage; 504 l/kg (live wt), with 93% of water from embodied feed usage.
GHG Production; 1.4 kg-C/kg live or 2.8 kg-C/kg processed product.

Comparison of Water, Energy, and GHG Footprint Aquaculture vs Livestock Production

Prototype	Water(liters/kg)	ENERGY (kw-hr/kg)	GHG(kg-C/kg)
RAS	504	13.7	1.4
Catfish	1,150- 3,628	4.5	0.5
Tilapia	2,460		1.5
Salmon	760-1,385	11.0	0.6-1.4
Bass	1515-2921	12.7	1.3
Trout		11.0	1.2
Asian Pond	454	0.10	0.4
Beef	7,703	34.5	9.7
Pork	2,994	14.0	1.65
Chicken	2,160	5.0	1.35

The direct and embodied water, energy and GHG emission footprint for prototype aquaculture system compared to alternative aquaculture and livestock production/kg live weight. **GHG gas production for beef is 6.7 times higher, and requires 15-fold more water per kg of live weight as opposed to aquaculture production. RAS trades water for energy vs pond fish production**

Energy cost vs type of production



SUMMARY

RAS energy, 5.0 kwh/lb (fish) to 15 kwh/lb (shrimp) as opposed to 8 kwh/lb (chicken), 24 kwh (pork) and 35 kwh/lb (beef).

RAS GHG, 14%, water 6.5% and energy 14/43% of **beef/kg**.

RAS GHG 85%, water 17% and energy 20/62% of **pork/kg**

RAS GHG 104%, water 23% and energy 63/188% of **chicken/kg**

Potential Global Impacts of Aquaculture

Threats (external costs)

Wild-caught fish used in fish meal
Pesticides, heavy metals in water/product
Nutrient enrichment/eutrophication of water
Wild seed-stock harvest
Habitat modification/destruction
Aquatic disease, pathogens, parasites

Remedies (direct costs)

Fish-meal replacement/substitutes
Regulatory system to mitigate impact
Hatchery for seed production
Proper siting
Zero-discharge RAS

U.S. consumption of lower-cost (imported) seafood enables global impacts while restricting U.S. aquaculture development

Algal Production and Harvest
for
Food, Feed and Biofuels

D. E. Brune [1], T. Lundquist [2] and J. Benemann [3]

[1] Professor and Endowed Chair, Dept. of Agri & Biol.Engr., Clemson University

[2] Assistant Professor, Califonia Polytechnical University, California

[3] Manager, International Network Biofixation of CO_2 & GHG Abatement with Microalgae,Walnut Creek, Calif.

Brune appointments/projects

University of Missouri (2009-present) Marine Shrimp Culture, Zero-discharge, Climate-Controlled Aquaculture, Aquaculture LCA, Split-Pond, PAS and Intensively Aerated Catfish Culture, Algal bioenergy, Water quality Treatment Systems

Clemson University (1987-2009) Partitioned Aquaculture Systems, Biofloc Marine Shrimp Production, Crawfish Aquaculture, Algal Bioenergy Production, Brine Shrimp Production

Pennsylvania State University (1982-1987) Recirculating Trout Production, Anaerobic Digestion, Wastewater Treatment, Freshwater Prawn Production, Brine Shrimp Growth for Algal Harvest

University of California-Davis (1978-1982) Algal Biomass Production, Brine Shrimp Production, Trout Production, Biofilter design, Lobster production, Seaweed gasification

University of Missouri (1975-1978) Anaerobic Digestion, Algal Growth Kinetics

Oregon State University (1975) Algal Culture on Swine Wastewater

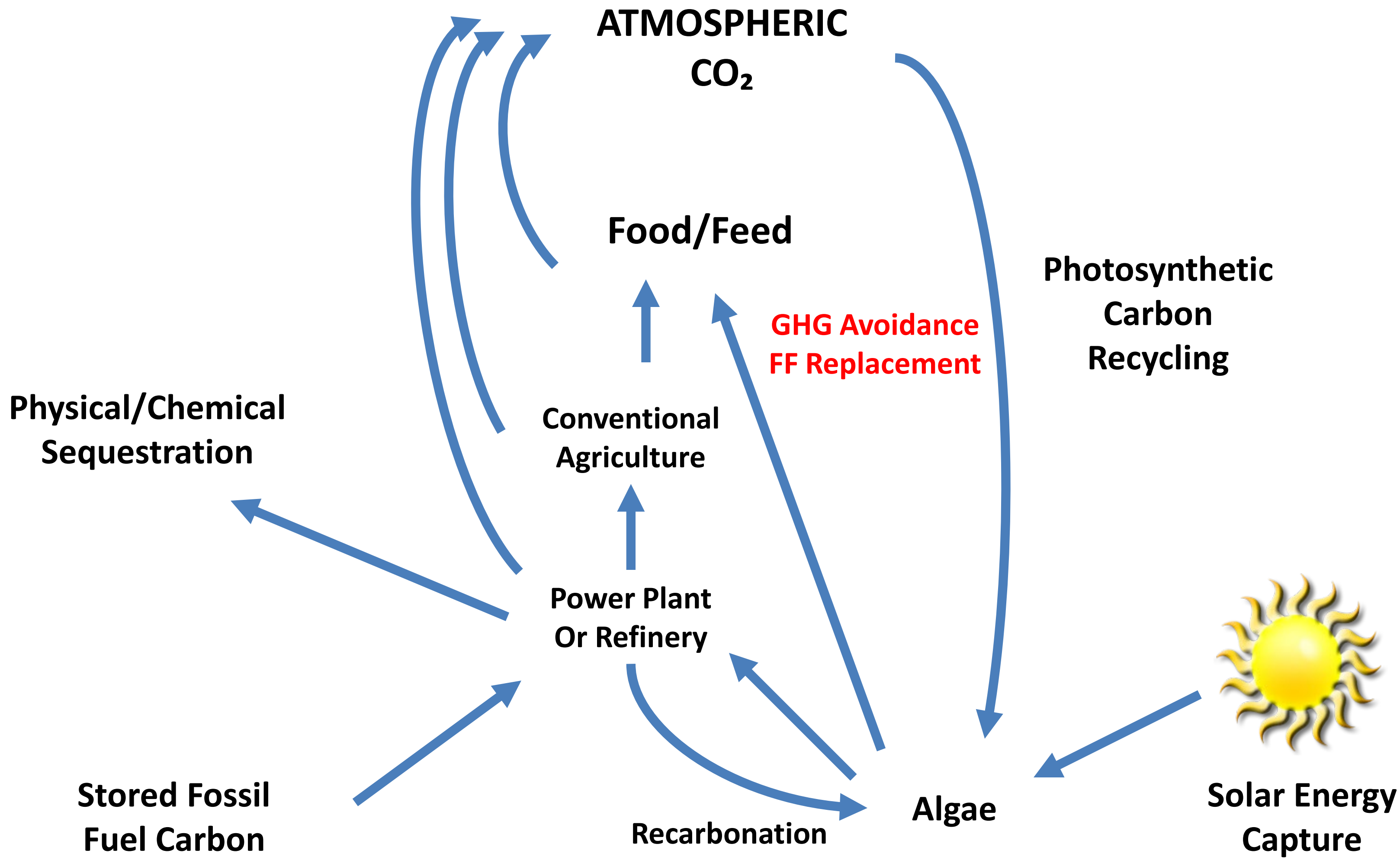
Why Algal Culture?

Good

- 4-5 X productivity over conventional crops
- Growth in brackish/saline water
- Production on under-utilized lands
- Fluid transport/handling
- Production at low nutrient concentration
- Short algal cell generation time

Bad

- Difficult to harvest, concentrate and dry
- Requires intensive processing to be useful
- Culture system capital investment high

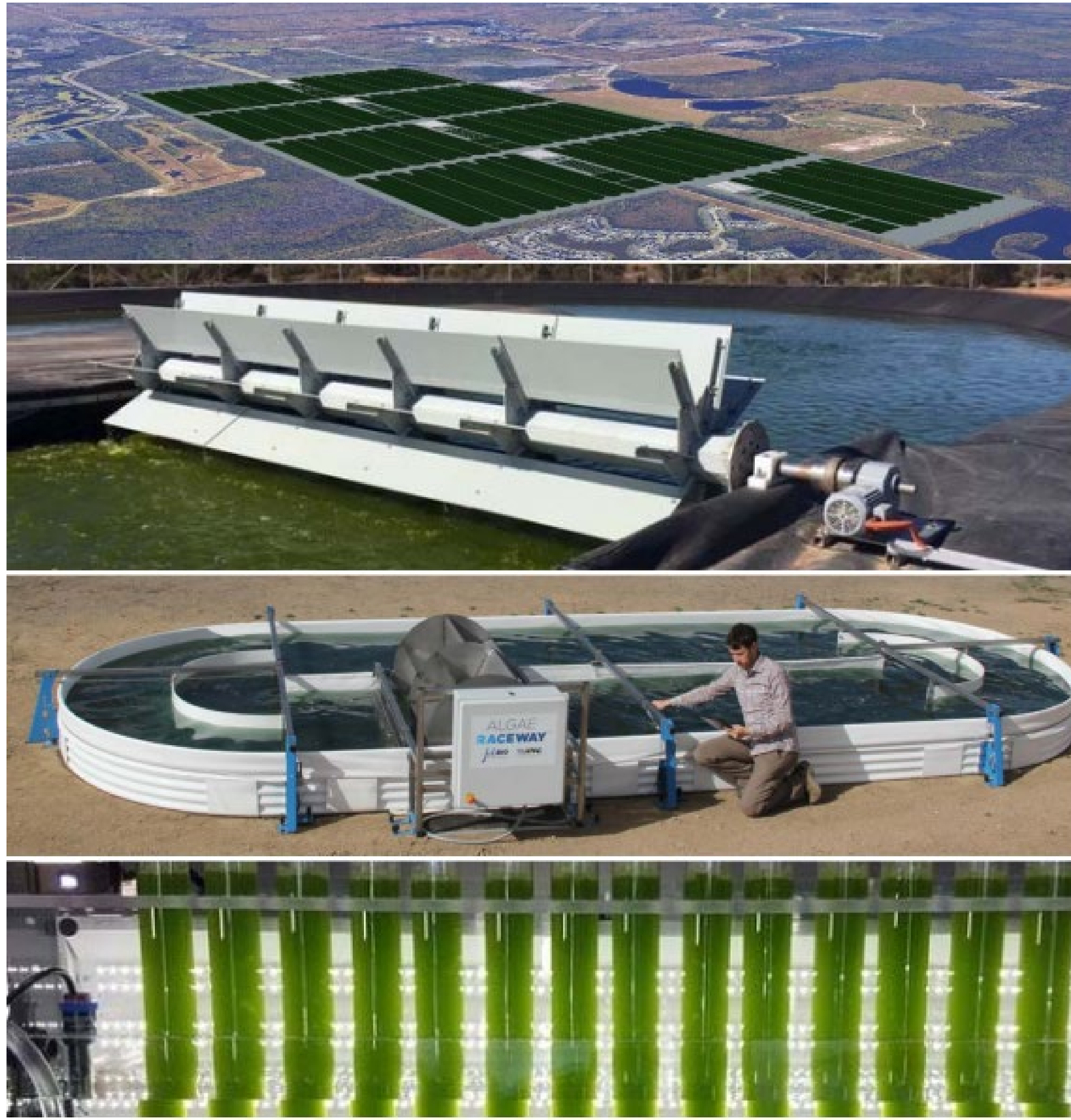


Algae for Carbon Avoidance, NOT Sequestration

Must be ENERGY EFFICIENT

Clemson System; Lowest Cost

- Open ponds, paddlewheel driven
- Tilapia stabilized
- Brine shrimp harvest
- Anaerobic digestion for methane



Brine shrimp harvest/conversion; 9% algal oil to 20% brine shrimp oil @ 50% efficiency

High-Density Brine Shrimp Culture at MU

BS reactors, 4,000 brine shrimp/liter, air-pulsed screen containment

Algae maintains water quality supporting 25,000 lb/acre shrimp production. Brine shrimp harvest/converts algae to 12,500 lbs/acre fishmeal co-production, with 4 kw/acre of stationary power (as biogas from solids) 25-50% of energy required to operate systems.

Brine Shrimp Harvest

20 days; harvested with dip-nets
De-watered *Artemia* biomass
60% protein and 20% lipid

Conclusions

We'll **NOT** be successful promoting system designs focused primarily on biofuels, bioenergy, or sustainability

….. given current economic constraints

We must develop systems supporting capacity for,

- Byproducts with nutrient recovery and recycle
- Maximize resource use/energy efficiency
- Target environmental remediation within current FF economy
- With potential for transition to solar-based production

HIGH-RATE CATFISH FINGERLING PRODUCTION IN THE PARTITIONED AQUACULTURE SYSTEM

D. E. Brune and Tim Wells
Dept. of Agricultural & Biological Engineering
Clemson University, Clemson, S. C. 29634

PAS Fingerling Production (2005)

Continuous water exchange

Continuous feed application

Captive Population
Improved harvesting/sorting
Improved health management/vaccine delivery
Predation elimination
Fingerlings = 100+ gms/season vs. 30-40 gms


Fingerling production tanks within PAS

3/16 inch mesh net-pens followed by 1/4-inch mesh net pens placed in cells

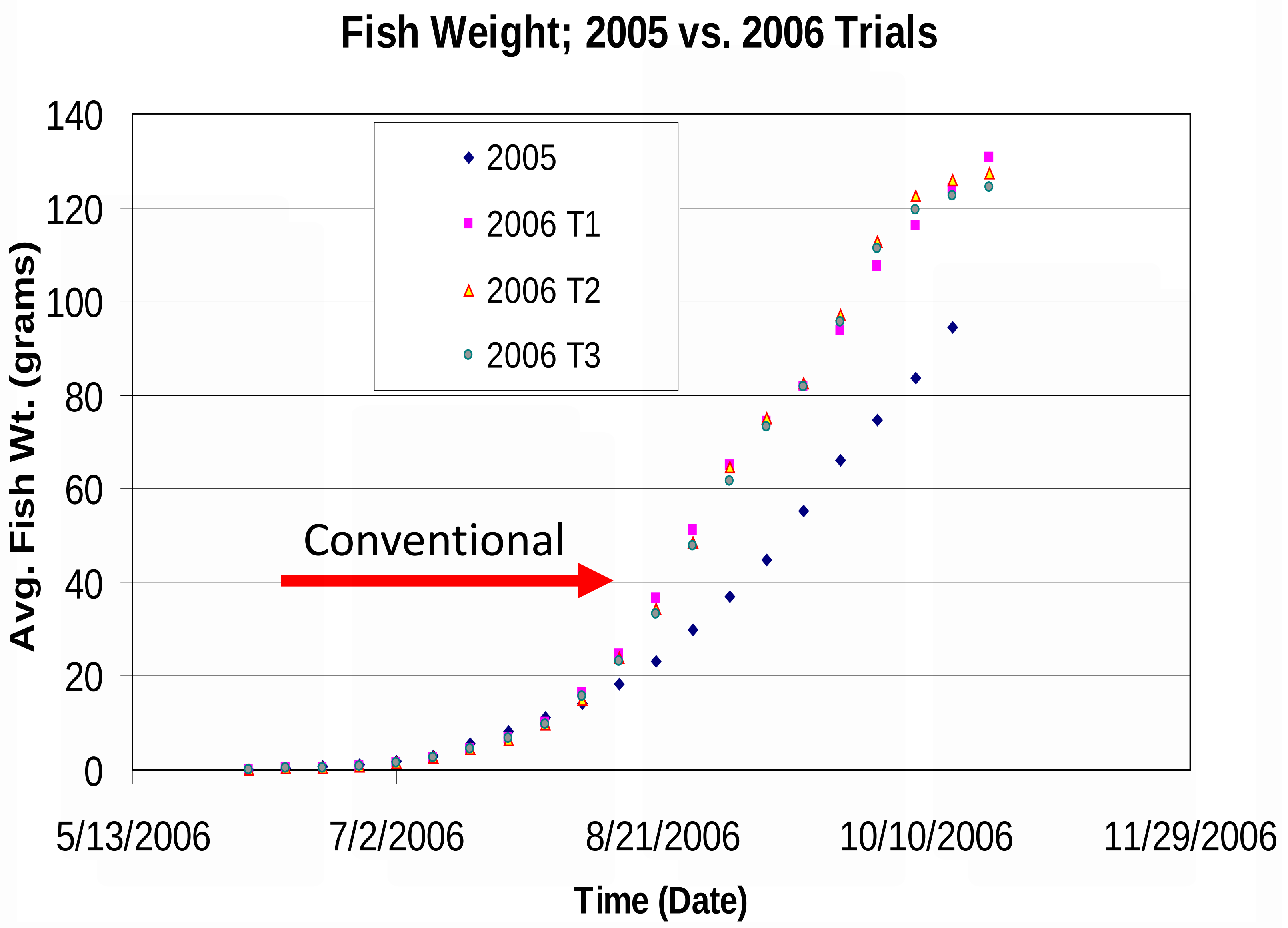
¾ hp pumping and 2 inch-airlift pumps

Continuous Automated Belt Feeders

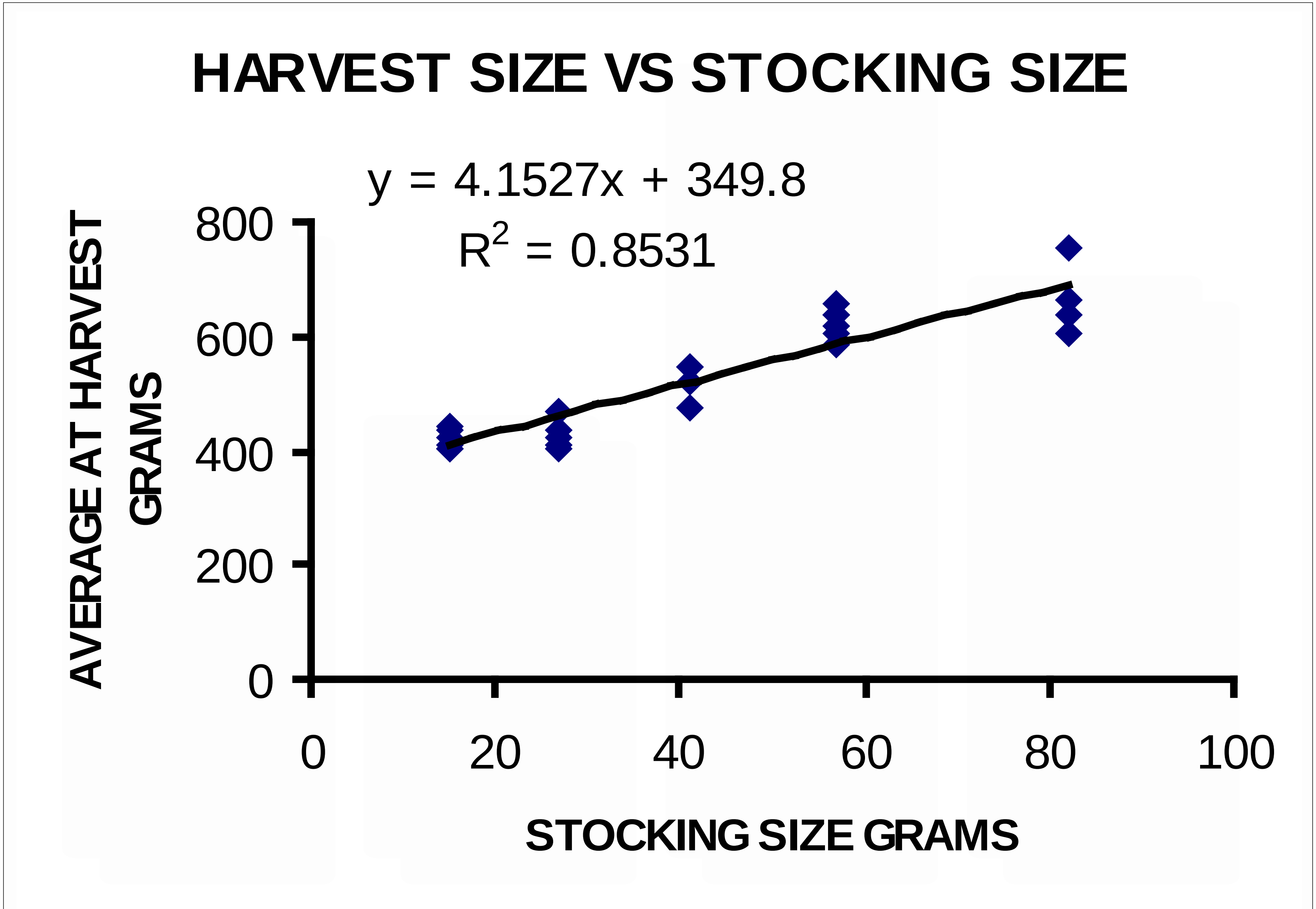
With automated feeders in place
Fry start in bins, then transfer to tanks

Fry Stocking

145-day Catfish “Fingerlings”



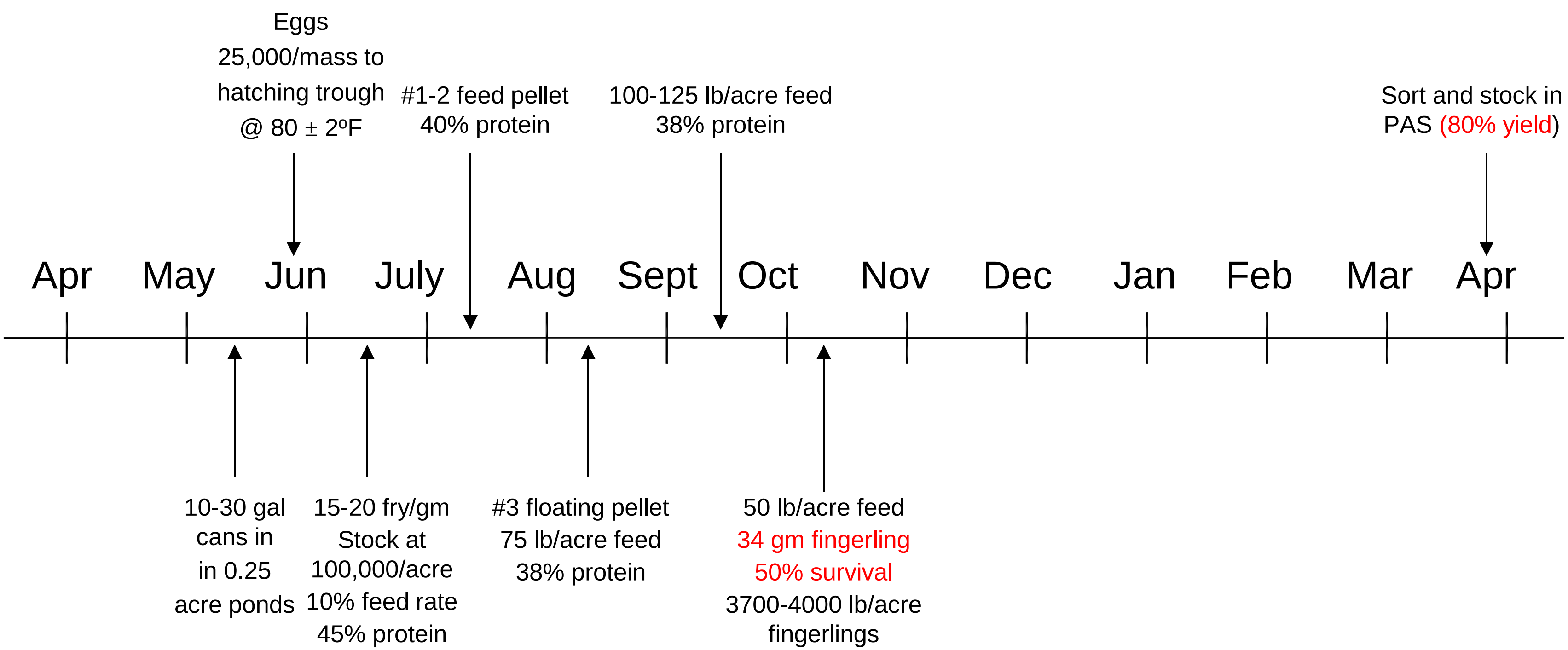
Conventional pond reared = 30-40 gms


HARVEST SIZE VS STOCKING SIZE
y = 4.1527x + 349.8
R2 = 0.8531
AVERAGE AT HARVEST GRAMS
800
600
400
200
0
0
20
40
60
80
100
STOCKING SIZE GRAMS

Conventional Pond Fingerling Production

34 gm, 50% survival 4,000 lb/acre

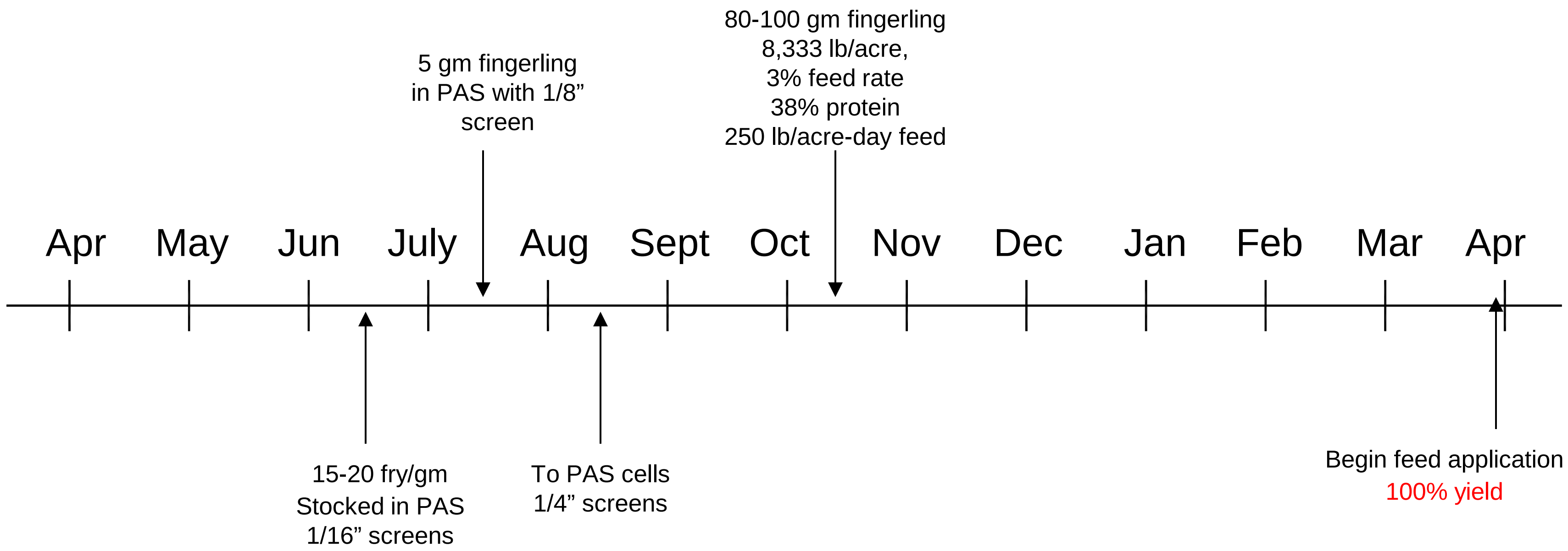
leading to 20% carryover after 2nd year grow-out



PAS Fingerling Production

100 gm 95% survival 8,000 lb/acre

leading to 100% harvest after 2nd year grow-out



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