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Sustainability has become the recent "buzz-word" in aquaculture and agriculture. As Claude Boyd indicated in San Diego (Aquaculture '95), aquaculture is not truly sustainable because aquaculture relies on external feed, chemical, and energy inputs. The United States Farm Bill of 1990 more narrowly defined the key components of sustainability as: maintaining profitability, supplying food and fiber needs, using non-renewable resources efficiently, enhancing renewable resources, and improving the quality of life in rural areas.

Intensive aquaculture practices have pushed production as high as 7,000 to 10,000 lb/acre. The objective has been to increase profitability by maximizing harvest weight (biomass) per unit volume/area of production system. However, these practices almost always exceed the biological carrying capacity of the production unit. As with feedlot livestock production, overcrowding usually leads to problems with environmental degradation, disease, off-flavor (aquatic animals), and a reduction in individual performance of the cultured species. In several instances (e.g., shrimp farming in Bangladesh, China, Taiwan, and Thailand), the long-term results of intensive production practices appear to have been economically and (potentially) environmentally devastating.

While the U.S. catfish farming industry has not experienced the catastrophes observed in the shrimp farming industry, it has manifested several of the warning signs that indicate production is at the upper limits of carrying capacity. Widespread disease, antibiotic-resistant bacteria, off-flavor problems, and routine aeration have become common for intensive channel catfish culture.

In recent years, Enteric Septicemia of Catfish (ESC) has flourished in the crowded production ponds of Mississippi. Off-flavor results from dense phytoplankton (algae) blooms and micro-organisms that accompany the heavy nutrient and organic loads produced by fish wastes (ammonia and manure) and uneaten feed. On any given day during the catfish production season, as many as 40–60% of the ponds sampled can contain off-flavor fish. Nighttime aeration, throughout the summer, has become the standard not the exception—because oxygen demand exceeds the natural regenerative processes of the pond environment.

SUSTAINABLE OR LOW-MANAGEMENT CATFISH PRODUCTION

For the purposes of this discussion, sustainable aquaculture will be viewed as commercial channel catfish production that:

- respects the biological or ecological limits of the production pond;
- requires minimal external inputs; and
- can be conducted with limited technical skills.

To quote Greg Henson, Extension Agent for Agriculture in McLean County, this is fish farming that can be "done with a 5-gallon bucket and a pick-up truck (or horse-drawn cart)" and without quitting the day job. The underlying concepts are:

- maximize biological efficiency in the production pond environment without exceeding natural carrying capacity;
- reduce the cost of production; and
- establish profitable, low-management production techniques for catfish.

Several field demonstrations have been conducted in Kentucky to examine the feasibility of improving production efficiency and pond yields using low stocking density and modified feeding practices. Altering the time of year for stocking channel catfish fingerlings was also explored. The primary objectives were to: take advantage of cool-weather growth; closely match feeding with actual catfish growth; and keep pond biomass at or below natural, pond carrying capacity (approx. 1,500 lb/acre) during critical periods—the hot weather experienced from July through mid-September. A secondary objective was to avoid heavy nutrient loads from fish waste products and uneaten feed.

Autumn Fingerling Stocking

The project demonstrated that autumn stocking increased channel catfish fingerling weight by 70– 90% between the beginning of October 1991 and mid-April 1992. Fish were stocked in 0.5- and 1.0-acre ponds. Fingerlings (0.1 lb each) were stocked at 2,000 fish/acre. Feeding, at 1–3% of biomass, was adjusted in accordance with standard temperature-based recommendations. Surface water temperatures reported for a large, local reservoir (Lake Barkley) were used to adjust feeding.

Channel catfish fingerlings (0.1-lb) are in their rapid growth (exponential) phase. By stocking fingerlings in early autumn rather than the following spring, they benefit from cool-weather feeding (when water temperatures are > 50°F). Fingerling growth is reduced but still good during cool weather. Because temperature and biomass are low, pond carrying capacity is not taxed. In western Kentucky, water temperatures are usually below 50°F from mid-December to early March.

Low-density, autumn stocking in combination with temperature-based feeding substantially increased channel catfish fingerling wieght by the subsequent spring. The advanced spring fingerling size (0.19-lb) allowed production of a 1.45-lb food-fish (1,343 fish/acre) in 180 days. These findings exceeded expectations for single-season, catfish growth in northern latitudes of the southeastern United States. This was accomplished by a "first-time" fish farmer, a teen-age boy still in high school.

Table 1. Channel catfish feeding table predicting catfish weights and daily feeding rates at 7-day intervals, assuming exponential growth for 0.1- to 0.53-lb fish and linear growth for fish >0.53 lb (1.0 lb = 454 g). Daily feeding is capped at 30 lb feed/acre.

Fish size (lb)	Fish size (K)	Time (days)	1,500 fish Wt (lb)	1,500 fish Feed Fed (lb)
0.10	45	0	149	4.5
0.12	54	7	179	5.4
0.15	68	14	225	6.7
0.19	86	21	284	8.5
0.23	104	28	344	10.3
0.29	132	35	437	13.1
0.35	159	42	526	15.8
0.43	195	49	645	19.3
0.53	240	56	794	23.8
0.59	270	63	892	24.2
0.66	299	70	990	24.6
0.73	329	77	1088	25.0
0.79	359	84	1187	25.5
0.86	389	91	1285	25.9
0.92	418	98	1383	26.3
0.99	448	105	1481	26.7
1.05	478	112	1579	27.1
1.12	507	119	1678	27.5
1.18	537	126	1776	27.9
1.25	567	133	1874	28.3
1.31	596	140	1972	28.8
1.38	626	147	2070	29.2
1.45	656	154	2169	29.6
1.51	685	161	2265	30.0

Low-Density Stocking and Modified Feeding

These two practices were demonstrated through the use of mathematically generated feeding tables (Table 1) and low stocking density (1,500 fingerlings/acre). Growth was assumed to be exponential for fish weighing from 0.1–0.53 lb each and linear for larger (> 0.53 lb) catfish (Fig. 1).

Channel catfish with an average, individual weight of 1.3 lb (1.0 lb = 454 g) were produced within 175 days using low stocking densities and tables to adjust feeding. These studies were done in 2.25- and 2.5-acre ponds. Catfish fingerlings were 0.1 lb each at the beginning of the study, 21 April 1993. Ponds were sampled and partially harvested on 14 October 1993.

Fish were fed a 32% protein, floating commercial catfish diet. Daily feeding was capped at 30 lb feed/acre but could go as high as 35 lb/acre. Fish were fed once each day. Feed was offered when dissolved oxygen would be highest, late afternoon or early evening. Feeding rates were adjusted every 7 days (Table 1).

After 175 days, survival was estimated to be greater than 95% and biomass to be 2,000 lb/acre. Food conversion ratios were 1.68 and 2.0. Fish weights as well as projected pond yields and food conversion ratios were 25–30% better than traditional expectations for channel catfish production in Kentucky. Projections and estimates were based on mean, individual weights and daily feed consumption, measured at the end of the study. It is interesting to note and perhaps the most important information collected; this was accomplished by a "first-time" fish farmer who had no university training.

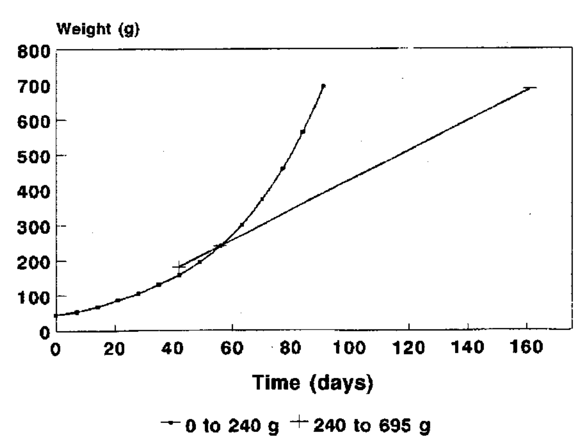

Fig. 1. Predicted channel catfish growth for 0.1-lb fingerlings stocked at 1,500 fish/acre.

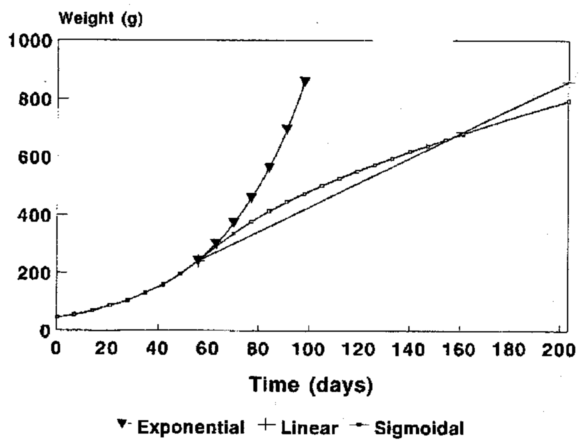

Fig. 2. A comparison of predicted sigmoidal (natural), exponential, and linear growth patterns for 0.1-lb channel catfish fingerlings stocked at 1,500 fish/acre.

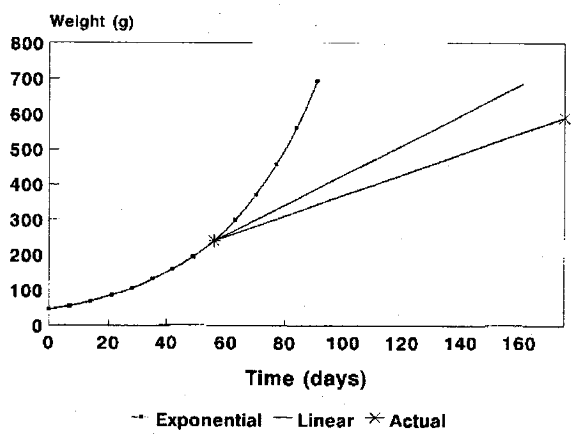

Fig. 3. Predicted growth compared with mean harvest weight for 0.1-lb channel catfish fingerlings stocked at 1,500 fish/acre in 2.25-acre and 2.5-acre ponds.

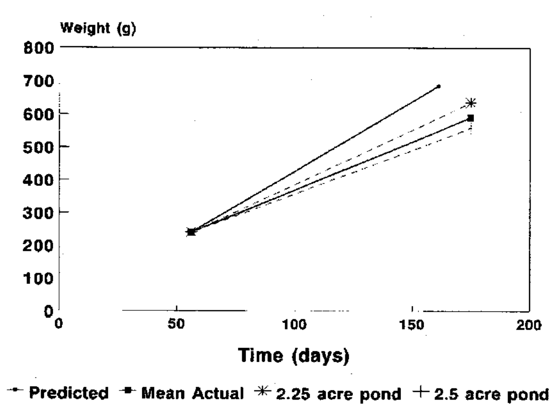

Figure 4. A comparison of predicted and actual mean harvest weights for 0.1-lb channel catfish fingerlings stocked at 1,500 fish/acre in 2.25-acre (0.9-ha) and 2.5-acre (1.0-ha) ponds.

Table 2. Channel catfish feeding table predicting catfish weights and daily feeding rates at 7-day intervals, assuming growth is exponential for fish between 0.1-0.7 lb each and linear for fish > 0.7 lb (1.0 lb = 454 g). Daily feeding would increase by 0.52 lb every 7 days for fish > 0.7 lb each and would be capped at 35 lb feed/acre.

Fish size (lb)	Fish size (g)	Time (days)	1,500 fish Wt (lb)	1,500 fish Feed Fed (lb)
0.10	45	0	150	4.5
0.13	58	7	195	5.9
0.16	74	14	240	7.2
0.21	95	21	315	9.5
0.27	121	28	405	12.2
0.34	154	35	510	15.3
0.43	197	42	645	19.4
0.56	252	49	840	25.2
0.71	322	56	1065	26.6

It is likely that channel catfish growth is truly a sigmoidal pattern (S-shaped curve, Fig. 2). However, an S-shaped growth curve is approximated reasonably well by an exponential curve followed by a straight line (Fig. 1 and 2). The math for linear and exponential equations is much easier to handle than the math for a sigmoidal function. Retrospectively, it seems that channel catfish growth is exponential (rapid) a little longer (up to a 0.7-lb fish) and more rapid than was originally assumed (Fig. 2 and Table 2).

Combining Low-Density And Autumn Fingerling Stocking with Modified Feeding

The results of these demonstrations suggest individual channel catfish growth is rapid from 0.1 to 0.7 lb (50–60 days) and then slows for larger fish (Figures 2, 3, and 4). Therefore, the most critical time to feed accurately is during the first 2 months of the spring-summer production season. Mathematically generated feed tables improve production efficiency by allowing the farmer to closely match feeding with natural growth rates. Nitrogenous and organic wastes as well as uneaten feed would be minimized because the amount of feed offered is not in excess of that needed for good growth.

Stocking fingerlings in autumn produces larger fingerlings and food-fish by the subsequent spring and autumn harvest, respectively. Catfish fingerlings stocked at the beginning of October (1,500 fingerlings/acre) could easily attain a weight of 1.50 lb each and a total biomass of 2,250 lb/acre by October of the following year. Continued feeding until December (up to 35 lb of feed/acre daily) in conjunction with periodic, size selective harvest (fish > 1.25 lb each) through mid-spring of the next year could further increase pond yields. Second-season fingerlings would be autumn stocked "under" harvest-size catfish. These fingerlings could consume uneaten feed and natural foods left by the larger, first-season catfish—improving net feed utilization.

Because low fish biomass and the use of feeding tables limits waste production, the nutrients released would stimulate (fertilize) pond productivity rather than pollute it. It is generally accepted that fertile ponds will support 300–600 lb of fish/acre without additional feed or energy inputs. Low stocking density allows fish to take advantage of naturally available food organisms in addition to commercial feed. In theory, the fish manure and uneaten feed associated with 1,500 fish could support sufficient aquatic life (insects, crustaceans, worms, etc.) to support 500 lb/acre of bonus fish growth.

A general estimate for channel catfish production is to assume that 1.0 lb of food-fish will be harvested for each fingerling stocked. Using this projection, 1,500 fingerlings could be expected to yield 1,500 lb/acre. The estimated biomass of the low stocking density demonstration was 2,000 lb/acre—500 lb/acre more than generally accepted. It seems plausible that this bonus growth is related to an increase in pond fertility (natural foods) promoted by fish wastes, and efficient (table) feeding. Low biomass (fish density), efficient feeding (good growth and limited wastes), and nutrient (fish wastes) stimulated fertility take full advantage (improved efficiency) of the pond ecosystem without exceeding biological and environmental limits.

SUSTAINABLE LOW-MANAGEMENT PRACTICES

It seems feasible that a combination of low-density, autumn stocking (1,500 fish/acre), table feeding, and continuous size selective harvest from autumn through spring could produce catfish yields as high as 2,250 to 3,000 lb/acre. Ponds are not aerated because biomass and oxygen demand do not become critical during hot weather. However, feeding is stopped during periods of low oxygen and resumed when fish begin feeding aggressively again. Disease is not treated except in the case of a serious outbreak—low fish density minimizes stress as well as disease occurrence and spread. Low biomass and limited waste production promote pond fertility and natural foods while maintaining acceptable water quality. Heavy nutrient and organic loads are absent, and the likelihood of off-flavor problems is reduced. All of this can be "done with 5-gallon buckets, a team of horses, and without quitting the day job."

INTENSIVE CHANNEL CATFISH PRODUCTION

Intensive catfish production techniques leave little room for error and can be unforgiving for the novice. Withholding antibiotics during a disease outbreak or eliminating summer aeration is likely to cause a 50–100% fish-kill in intensive production systems. With the low management approach, not treating a disease or no aeration might result in a 5–10% fish loss, possibly 25% under unusual circumstances.

As the number of pounds of catfish produced per acre increases, the cost to produce a pound of fish increases. A catfish yield of 4,500 lb/acre requires significant external inputs: energy (e.g., aeration), chemicals, antibiotics, feed, time, labor, etc. These additional inputs cost money and cut into potential profits. There is a point at which additional inputs do not increase yields and profits sufficiently to offset the extra costs and "risk" involved. Somehow, intensive aquaculture seems to have avoided the close scrutiny of "the economics of diminishing returns."

The basic costs for low-management catfish production, feed ($630; $0.14/lb) and fingerlings ($225; $0.15/fish), would be $855/acre. Similar costs for intensive production, feed ($1,260; $0.14/lb) and fingerlings ($675; $0.15/fish), would be $1,935/acre. Using the basic costs above and a wholesale catfish value (live-weight) of $0.80/lb, low-magagement production would yield 2,250 lb fish/acre worth $1,800 and intensive production would generate 4,500 lb/acre worth $3,600. Net profit (harvest value minus "basic costs") would be $945/acre and $1,665/acre for low-management and intensive farming, respectively.

A few hundred dollars profit per acre is significant when considering a 1,000-acre channel catfish operation. However, deducting the costs associated with aeration, antibiotics, algicides, and a 15% fish loss would substantially reduce the profit/acre for intensive practices. The additional costs and risk of intensive catfish farming might not be acceptable for the 1.0- to 5.0-acre producer.

Marketing more than a few thousand pounds of fish requires wholesale pricing, bulk sales, and large-scale processing. The opportunities for local retail sales ($1.25/lb, live-weight) are more realistic when working with the smaller harvest of a low-management, channel catfish business. Similarly, retail sales can provide greater net profits, as high as $1,950/acre, for 1.0- to 3.0-acre farms.

TOWARDS THE FUTURE

Ninety thousand individuals, each farming a "low-management," 2.5-acre channel catfish pond, could surpass the total annual channel catfish production for the southeastern United States in 1993 (440 million pounds). Future producers may improve pond efficiency further by incorporating filter feeding fish and molluscs into sustainable low-management systems; taking advantage of the plankton populations present, yet largely unused, in catfish production ponds. Furthermore, new technology may radically redefine the production unit as we know it.

Undoubtedly, competition for aquatic resources will continue to escalate in the 21st century. Moderate increases in the cost of electricity or petroleum-based fuels could significantly affect the profitability of intensive fish production practices. Whether channel catfish production is done in high-tech raceways and recirculation units, intensively managed ponds or sustainable low-management systems; the practice used must be energy-efficient and environmentally sound. Ultimately, in order to benefit the most people, production technology must be user-friendly and practicable with limited resources. Bottom line, "keep it simple."

ACKNOWLEDGMENTS

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