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Chapter 10

INTENSIVE MANAGEMENT OF WATER FOR FISH PRODUCTION

R.O. Smitherman and C.E. Boyd

Abstract

Fish production in warmwaters of the Southeastern United States has been increased from approximately 100 pounds per acre in natural waters to 20,000 pounds per acre with intensive culture systems using artificial circulation, filtration and supplemental feeding. Intensification of fish production results in alterations of water quality. Changes in factors of importance to health and growth of aquatic organisms include phosphorus, organic and inorganic nitrogen, BOD and COD. Methods by which detrimental changes in water quality parameters have been combatted involve mechanical aeration, polyculture with secondary fish species to consume waste feeds and detritus, aquatic plants to absorb nutrients and prevent excessive phytoplankton blooms, and recirculation and filtration of water to minimize BOD and COD.

Introduction

Development of high-intensity culture of fish has lagged considerably behind that of land animals such as cattle and poultry partially because aquatic organisms live in an environment foreign to man, and consequently one which is poorly understood. Fortunately, much methodology can be adapted from the several animal sciences in agriculture, but special problems arise because fish are poikilotherms. Temperature, interrelated in a complex way with water quality, photoperiod, food supply, and space influence growth rate, reproduction, and susceptibility to diseases.

Intensive cultures of fish, with populations much more dense than in nature, create unique problems, among them nutritional inadequacies, facility of disease transmission, and increased oxygen demand arising from metabolism of the biota and from feeding wastes.

Research over the past 40 years at the Agricultural Experiment Station has been oriented toward producing ever higher yields of fish and other aquatic organisms, and problem-solving in areas presenting constraints to the development of aquacultural industries.

Fish Production at Various Levels of Culture

Fish production in natural waters is dependent upon fertility of soils of the watershed (33). This production, expressed as standing crop of fish, has been reported at levels of 24-482 pounds per acre in Alabama streams (26) and 47-125 pounds per acre in unfertilized ponds in the Piedmont region of Alabama (21,

When fertility of water was artificially increased by additions of inorganic nutrients standing crop of bluegill (Lepomis macrochirus Rafinesque) was raised as high as 588 pounds per acre (21). Combinations of bluegill and largemouth bass (Micropterus salmoides Lacepede) in ponds receiving organic and inorganic fertilizers yielded up to 437 pounds per acre (25). Other species, buffalofish (Ictiobus spp.) and Tilapia spp., which feed directly on plankton, produced 1,000-1,500 pounds per acre in fertilized ponds (29).

Fish production is further increased by supplemental feeding, and various forms of aeration. The following yields have been realized at Auburn University using various experimental systems of culture:

Species	Culture System	Standing crop (lb /A)	Duration (months)	Author
Bluegill-Bass	Pond	1,129	42	Schmittou (19)
Tilapia	Pond	1,793-4,389	6	Swingle (28)
Channel catfish	Cages in pond	2,007	5	Schmittou (20)
Channel catfish	Pond/water hyacinths	2,720	8	Lovshin (14)
Channel catfish	Pond	3,412	7	Prather and Lovell (18)
White catfish (*Ictalurus catus* L.)	Pond/aeration	6,600	7	Loyacano and Jeffrey (1
Channel catfish Tilapia	Pond/aeration	5,000 catfish 2,000 tilapia	6	Smith (22)
Channel catfish	Concrete ponds/ filtration and circulation	20,000	7	Greene (9)

Effects of Various Management Procedures on Water Quality

Water Chemistry

The chemical environment influences fish survival and production in ponds. The more common problems with water chemistry involve dissolved oxygen, carbon dioxide, pH, ammonia, and hydrogen sulfide. Most problems in water quality are related to low concentrations of dissolved oxygen. Requirements of dissolved oxygen for warm water pond fishes were summarized by Moss and Scott (17). Minimal oxygen levels for survival of bluegill, largemouth bass and channel catfish were approximately 1 mg/l. For health and optimum growth, fish culturists feel that oxygen should not drop below about 2-5 mg/l.

Carbon dioxide concentrations usually are inversely related to those of dissolved oxygen in pond waters. Ellis (7) indicates that most waters used for fish culture contain less than 4 mg/l carbon dioxide. However, concentrations up to 20-30 mg/l can be tolerated by fish provided oxygen is near saturation. At low levels of dissolved oxygen, toxicity of carbon dioxide increases.

Toxicity to pond fish from hydroxide ion concentration occurs below pH 4.0 and above pH 11.0. However, if pH values remain above 9.5 or below 6.0 for extended periods, fish will not grow well even though they may survive. Mineral acidity from acid mine drainage is usually responsible for pH values below 5, while waters with high concentrations of organic matter may be in the pH range of 5 to 6. Liming agents may be used to improve low pH. High pH conditions may sometimes be alleviated by use of acid-forming fertilizers such as ammonium nitrate or ammonium sulfate (27).

Ammonia concentrations above 1 mg/l as determined by the nesslerization procedure, generally indicate organic pollution. Un-ionized ammonia is detrimental or lethal to fish at concentraions of approximately 2.5 mg/l (8). Such conditions are relatively rare since the percentage of un-ionized ammonia is low within normal pH ranges of natural waters. At 25°C, the percentages of un-ionized ammonia are as follows: pH 7 - 0.7%; pH 7.5 - 1.73%; pH 8 - 5.28% ; pH 8.5 - 14.97%; pH 9 - 35.76% (34). For example, a water sample containing 5 mg/l of ammonia at pH 8.5 would contain only 0.75 mg/l un-ionized ammonia, and would not cause toxicity to fish.

Hydrogen sulfide has been implicated as the cause of death in fish exhibiting the unusual clinical sign of chocolate-colored blood.[1] Bonn and Follis (1) reported cases of hydrogen sulfide toxicity to catfish in ponds of northeast Texas. A LD_{50} of 1.4 mg/l of un-ionized hydrogen sulfide at pH 7 was recorded for adult channel catfish. The toxicity of hydrogen sulfide increases with decreasing pH. Most cases of alleged toxicity of hydrogen sulfide to fish were not substantiated by measurements of either pH or sulfides.

Fertilization

Natural waters in the southeastern United States generally contain low concentrations of nutrients and are unproductive of phytoplankton and fish. These waters may be classified as (i) those transparent waters which generally contain abundant growths of submersed plants, (ii) those turbid with suspended soil particles, and (iii) those stained with humic substances. Monthly applications of inorganic fertilizers at the rates of 40 lb /A of 20-20-5 will stimulate the production

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[1] Allison, R. 1973. Personal communication.

of microscopic plants. In ponds which have waters of low alkalinity (0 to 20 mg/l as $CaCO_3$) and acid bottom muds (pH less than 6), applications of 1 to 3 tons of agricultural limestone must be made before the pond will respond to fertilization. (32, 36).

The turbidity resulting from phytoplankton growth usually restricts light penetration to approximately 2 feet and essentially eliminates submersed aquatic macrophytes through shading.

Phytoplankton communities usually consist primarily of one or two species (2), whose numbers may fluctuate drastically in a relatively short period of time. Sudden decline in a species may greatly reduce the rate of oxygen production and in some cases result in fish mortality. Applications of superphosphate have been used to shorten the time of recovery to optimum phytoplankton density (30).

Collodial particles of muddy waters precipitate following stimulation of phytoplankton growth by inorganic fertilization (25). If clearing of waters is not effected by inorganic fertilizers, 1 ton per acre of organic matter, such as cottonseed meal, hay or animal manure, may be applied (12).

Waters stained by humic substances may be made transparent by liming preparatory to fertilization. Excellent accounts of clearing brown-stained waters by liming are given by Hasler, Brynildson, and Helm (10).

Excessive applications of inorganic fertilizers and accumulation of organic matter in old ponds may cause over-production of phytoplankton, especially the blue-greens, Cyanophyta, which causes shallow stratification. Overturns caused by cooling of surface waters by rains or by cool weather, and upwelling of oxygen-deficient waters caused by strong winds may lead to oxygen depletions and fish kills (30). Methods for prevention of fish kills include thinning of phytoplankton by adding 0.75 lb of copper sulfate per surface acre (6) and recirculation and agitation of pond waters to effect re-oxygenation (30).

Water Quality and its Improvement in Intensive Fish Cultures

Highest production of fish is attained through use of supplemental feeding, and the maximum attainable levels are regulated by the ability of the culture system to oxidize its wastes and maintain sufficient dissolved oxygen for fish growth and survival. An example of the wastes contributed to the waters of an intensive culture system by feeding can be illustrated for a 1-acre earthen pond which receives 3,000 pounds of fish feed during a 180-day growing season and yields 2,500 pounds of catfish:

Constituent added	% dry wt. Feed	fish	lb dry wt. Feed	fish	Feed not converted to fish (lb)
Dry matter	95	20	2,850	500	2,350
Nitrogen	6	12	171	60	111
Phosphorus	1	3	28	15	13

These wastes enter the water as a variety of substances, including carbon dioxide, ammonia, and undigested organic compounds and minerals. The organic consitutents create a considerable oxygen demand, and reduce the amount of oxygen available to the fish and other biota of the system. Inorganic nutrients, particularly nitrogen and phosphorus, which are contributed by the wastes cause dense phytoplankton growth and increase zooplankton production. Rates of primary productivity in catfish ponds receiving about 3,000 pounds of feed per acre averaged 5.32 g/m^2 of organic matter, or 8,500 pounds per acre during a 180-day growing season. The amount of organic matter produced by photosynthesis was about 4 times that contributed directly by the feeding wastes (3).

The biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) of nine fish ponds which received applications of fish feeds gradually increased with feeding rates. Maximum 5-day BOD values ranged from 8-10 mg/l and COD values from 30-80 mg/l (4). There was a corresponding increase in phytoplankton densities, indicating that the increases in BOD and COD were related to increases in phytoplankton growth rather than simply to wastes. This contention was verified when BOD and COD declined with decreased phytoplankton in the fall, even though feeding rates remained at maximum (40 pounds per acre per day). It should not be interpreted from these data that blooms of phytoplankton are undesirable in intensive culture systems. Except for systems which receive artificial aeration, photosynthesis must evolve sufficient oxygen to meet the oxygen requirements of the biota. Furthermore, failure to maintain turbidity will encourage growth of nuisance submersed weeds. However, the life cycle of phytoplankton is usually 1 to 2 weeks, and upon death and decay these plankters add to the oxygen demand. Quite often, off-flavors described as "earthy-musty" are detected in intensively cultured fish (13). These off-flavors have been attributed to blooms of blue-green phytoplankton and/or actinomycetes growing on detritus of the pond bottom. Efforts must be made to prevent excessive phytoplankton production and its attendant problems. Since herbicides other than copper compounds are not cleared by the FDA for use with food fish, other means of regulating phytoplankton production and supplying additional oxygen have been investigated.

Mechanical aeration. Using air blowers which released 150 cubic feet per acre per minute, Loyacano and Jeffrey (15) increased production of white catfish to 6,600 pounds per acre. Not only did this practice increase concentrations of oxygen to saturation, turbulence maintained a suspension of fine soil particles which restricted light penetration and phytoplankton production. Aeration at less than 150 cfm has been used to prevent stratification in larger ponds, but the economic feasibility is not known.

Polyculture. Smith (22) used *Tilapia aurea* in combination with channel catfish as agents to consume fine waste particles of feed offered the catfish, and as biofilters to control phytoplankton populations. Some of the young tilapia were also consumed by catfish. This was effective and oxygen demand in earthen ponds was reduced so that feed rates could safely be increased from 35 to 70 pounds per acre per day. Maximum yields of catfish were about 5,000 pounds per acre, with an additional 2,000 pounds of *Tilapia aurea*.

Water hyacinths [*Eichhornia crassipes* (Mart) Solms]. These floating plants will remove nutrients from the water and reduce phytoplankton production. In recent studies at Auburn University, water hyacinths were stocked in earthen ponds at rates of 0, 5, 10, and 25% of surface area. All ponds received applications of nitrogen and phosphorus. The competition between water hyacinths and phytoplankton can be illustrated by the following[2].

% Coverage by water hyacinths	Phytoplankton/ml
0	29,000
5	13,000
10	4,000
25	3,000

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[2] McVea, C. and C. E. Boyd. 1973. Unpublished data.

Recirculating biofilters. Biological methods similar to those utilized by municipal waste treatment facilities have been experimentally incorporated into fish production systems in an effort to clean and reuse water in intensive fish culture. Production up to 20,000 pounds per acre has been achieved in .005-acre ponds (9). However, costs of production of operation presently prohibit commercial use.

Raceways. In an effort to reuse water in fish culture, earthen raceways are employed as production units for channel catfish and rainbow trout, Salmo gairdneri Richardson (5). Water flows from a storage basin through the raceway to a settling basin where solids precipitate; subsequently, water from the upper levels of the basin is pumped back to the storage basin at the head of the raceway. Yields of up to 40,000 pounds per year per acre of raceway surface have been reported. The system contains additional acreage in the settling and storage basin. Preliminary estimates indicate that catfish production costs are similar to those of pond culture. Due to accumulation of wastes and consumption of oxygen, growth of fish decreases from upper to lower sections of the raceway system.[3]

Effluents from Warmwater Fish Culture

Hinshaw (11) expressed concern with the pollutional load of waters released from fish hatcheries and fish farms. To date, there has been no attempt to regulate the discharge of effluents from fish cultural activities. The following data from nine catfish ponds at Auburn University show some alteration in water quality, particularly increased levels of alkalinity, hardness, BOD, COD, and nitrogen compounds.

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[3] Hill, T. 1973. Personal communication.

Water Quality Parameter	Before culture (April) mg/l	At harvest (October) mg/l
pH	7.1	7.2
Total alkalinity	19	34
Total hardness	14	24
Soluble inorganic phosphorus	0.017	0.006
Total phosphorus	0.054	0.074
Nitrate	0.087	0.114
Ammonia	0.04	0.52
Kjeldahl nitrogen	0.60	1.43
BOD	1.27	3.51
COD	13.60	36.11

Unless the volume of effluent was great in relation to the volume of receiving water, it appears there would be little ecological change effected by discharge from these ponds.

Research Needs

The research priorities for intensive fish culture as developed by fisheries technicians throughout the Southeastern United States have been reviewed by Smitherman (23), and Smitherman and Corley (24). Primary effort should be directed to the improvement of water quality and toward maximum production of fish per unit of water. Several means through which this might be accomplished include: (i) development of concentrated feeds which are more completely converted to fish tissue (18), (ii) refinement of polyculture techniques to fully utilize waste feed and natural foods not used by primary culture species (35), and (iii) genetic modification of fish stocks for improved growth, food conversion and disease resistance (16).

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