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Water Quality in Commercial Channel Catfish Ponds and Its Receiving Water Bodies

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차넬메기 養魚場의 水質과 주변 自然 河川水와의 關係

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요 약

미국 알라바마주의 중서부 지역에 밀집되어 있는 차넬메기 양어장의 수질을 조사하여 양어장 물이 배출되는 그 주변 하천의 수질과 비교하였다. 양어장의 사육 밀도는 헥타르당 10,000 마리였으며, 밤동안 (0000－0600)에는 산소를 공급하기 위하여 수차를 사용하였고, 먹이 공급은 일주일에 6일 동안 하였다. 메기 양어장에서 방류되는 사육수의 오염 정도를 알아보기 위하여 양어장의 표층 30 cm와 저층에서 1990 년과 1991 년에, 계절별로 시료를 채취하여 수질 변수를 측정하였다. 수온, 용존산소, pH, 침전성물질, 총부유물질, 휘발성물질, 총인, 용존인, BOD, 총암모니아, 아질산염, 질산염, 그리고 총켈달질소의 평균값은 표층과 저층의 시료 사이에 차이가 없었다 (P>0.05).

양어장의 수질은 주변 하천수에 비해서 오염도가 높았으며, 특히 질소와 인의 농도는 아주 높았다.

INTRODUCTION

The world production of channel catfish was 184 thousand metric tons during the year of 1989 (USDA 1990). Production in the U. S. A. was 155 thousand metric tons in 1989 (USDA 1990) and 177 thousand metrtic tons by 1991 (USDA 1992). By judging the current level of aquaculture activity, catfish aquaculture will continue to expand and its yield will also increase over the next decade. However, fish farm effluents have long been considered a source of pollution in Europe (Alabaster 1982) and recent studies characterized the quantity and quality of fish farm effluents in European countries (Bergheim and Silvertsen 1981; Bergheim *et al.* 1984). Most European countries have developed regulations regarding fish farm effluents. Likewise, federal and state

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regulatory agencies in the United States are increasingly concerned with effluent discharges from aquaculture facilities. Effluents from channel catfish ponds are being considered as potential sources of water pollution because aquaculture ponds discharge effluents into natural waters, some pond effluents being heavily polluted.

Currently there is a lot of publicity about pond effluent discharges because of a desire to prevent water quality deterioration in natural waters. There is a need to collect more data on pond effluents so that the pollution potential of effluents can be better evaluated. However, there is a clear evidence from existing data that pond effluents often are more concentrated in nutrients and organic matter than receiving water bodies.

Several effluent-related studies have been conducted and the potential effects of effluents from both small and large farms have been discussed (Hinshaw 1973; Boyd 1978; Wheaton *et al.* 1979; Hollerman and Boyd 1985; Smitherman and Boyd 1985; Tucker and Lloyd 1985). Water quality in ponds deteriorates in response to high stocking density and high feeding rates (Lovell 1978; Sparrow 1981; Tucker and Boyd 1985; Milstein 1990). As feeding rates increase considerable amount of nitrate, ammonia, phosphate, and organic compounds can accumulate in ponds, thus water quality deteriorating and phytoplankton abundance increases. Boyd (1985) reported that production of each 0.45 kg of live channel catfish in experimental ponds required 0.6 kg feed and released to the water in metabolic wastes 51.1 g nitrogen, 7.2 g phosphorus, and enough organic matter to result in a chemical oxygen demand (COD) of 1.1 kg. Phytoplankton growth stimulated by nutrient from the metabolic waste results in organic matter production equivalent to 3.69 kg of COD.

Water use must also be considered when evaluating the environmental impacts of pond aquaculture. When effluents are released from ponds through overflow and intentional discharge, they contaminate surface waters downstream from ponds. Scientists have conducted researches on the pollutional load in water released from fish farms. Concentrations of total alkalinity, total hardness, total phosphorus (TP), nitrate, ammonia, Kjeldahl nitrogen, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are higher at harvest than before culture (Smitherman and Boyd 1974). Tackett (1974) conducted research on raceway systems with channel catfish and reported that the differences in concentration of water quality variables in the influent and effluent were small; however, suspended solids and BOD values were significantly increased in the effluent.

By law, in the United States, fish farmers can no longer discharge effluents from hatcheries or fish ponds into natural waters, because the effluents fall under provisions of the Water Pollution Control Act Amendments of 1972 (Brown *et al.* 1976) and the Clean Water Act (WPCF 1987). This legislation has resulted in the National Pollutant Discharge Elimination System (NPDES), which specify daily average and maximum levels of pollutants, discharge duration and periods, monitoring requirements and other conditions. Thus, effluent regulations will likely greatly modify water use in ponds and may result in fundamental changes in current ideas on production intensity.

The objective of this study was to assess and characterize water quality in channel catfish ponds by measuring selected water quality variables.

MATERIALS AND METHODS

This research was conducted in 25 commercial catfish ponds in Montgomery and Hale Counties, Alabama.

Channel catfish (*Ictalurus punctatus*) was the species used for this study. Average pond depth was 1.5 m. They were fed daily, six days per week, with commercial floating feed (32% protein ratio) at a rate of 3% body weight per day. Maximum daily feeding rate was 130 kg per hectare. Feeding rates were adjusted every 2 weeks for weight again and as required for fish mortality. Depend on pond size, one or two 1.0-horsepower electric paddle wheel aerators were used. Aerators were operated daily from midnight to 0600 from mid-May until harvest. Whenever DO fell below 3 mg/ℓ at down and below 7 mg/ℓ at 1500 to 1600, additional aeration was supplied for safety.

Two water samples were collected from each pond on each sampling date, near the end of each calendar season, fall in 1990 and winter, spring, and summer in 1991. One was dipped from the surface at a depth about 30 cm and the other pumped from near the pond bottom with a portable hand-held pump (Black & Decker Inc., Hampstead, Maryland) in the area of the drain pipe.

Water temperatures and dissolved oxygen concentrations were measured with a polarographic oxygen meter (model 57, Yellow Spring Instrument Co., Yellow Spring, Ohio). Water samples were analyzed for the following variables by standard procedures described in Standard Methods of Waste and Wastewater Analysis (APHA *et al.* 1989) : settleable solids(SS) - Imhoff cone-volumetric method; total suspended solids (TSS) - filteration followed by gravimetric analysis; volatile solids (VS) - filteration followed by ignition; total ammonia nitrogen (TAN) - phenate method; nitrate (NO_3) - cadmium reduction, followed by spectrophotometry; nitrite (NO_2) - colorimetric method; Kjeldahl nitrogen - macro - Kjeldahl method; biochemical oxygen demand (BOD) - standard BOD_5; pH - glass electrode. The following variables were analyzed by the procedures described in Boyd (1979) : total phosphorus (TP) - persulfate oxidation followed by spectrophotometry; and soluble reactive phosphate - molybdenum blue method.

Mean water quality variables from selected streams in Alabama were given by Moore and Richer (1985, 1986) and Moore (1987, 1988, 1989, 1990). Water quality data for streams in the vicinity of the fish farms from which water samples were taken in this study were used as an indication of typical water quality in receiving bodies of water.

Descriptive statistics, ANOVA, two-way ANOVA, regression analysis, chi-sqaure, and Duncan's multiple range tests were employed to analyze the data with use of Statview, and SAS statistical software package (SAS Institute, Inc. 1985, 1986). All statements of statistical significance refer to $P>0.05$.

RESULTS AND DISCUSSION

Means and ranges for water quality variables in samples of water collected from the surface and near the bottom of 25 commercial channel catfish ponds in central and west-central Alabama during four seasons are reported in Table 1. These ponds were all stocked at the rate of about 10,000 fish per hectare which is the normal stocking rate for Alabama fish farmers. Ponds included both watershed type and levee type construction.

Water quality variables varied greatly among ponds and with season. However, there was little difference in concentrations of most variables between the surface and bottom waters of ponds. This resulted because aeration of pond prevented development of stable thermal stratification. Concentrations of water quality variables in the commercial ponds usually fell within the same ranges of water quality values reported for the ponds in the experiment on harvest technique (Boyd 1978). Water temperatures varied with season from 10.0 to 33.0℃ at the surface and 9.5 to 32.0℃ near the bottom. Dissolved oxygen (DO) concentration is usually the most critical water quality variable in pond aquaculture. Several times, aeration did not prevent DO concentrations from falling below 3 ㎎/ℓ in the early morning. The DO concentrations ranged between 2.6 to 16.8 ㎎/ℓ at the surface and 0.8 to 12.7 ㎎/ℓ near the bottom. These wide fluctuations in DO reported typical in ponds used for intensive fish culture (Malca 1976; Boyd 1982b). Mean DO values were not different between the samples of the surface and near the bottom ($P>0.05$). Concentrations of DO increased when the water temperature decreased in fall. Mean BOD_5 values gradually increased as feeding rates increased with time during the study. There were no significant differences in mean BOD_5 values between the samples of the surface and near the bottom ($P>0.05$). The high BOD_5 in pond water might resulted from an abundance of phytoplankton as revealed by high chlorophyll a concentrations (Boyd 1979). Total phosphorus (TP) ranged from 0.218 to 2.540 ㎎/ℓ in samples collected in the fall. Surface water samples had average concentrations of total phosphorus of 0.208 ㎎/ℓ in the spring as compared to 0.370 ㎎/ℓ in the summer. Most of the phosphorus input to the ponds was from the feed applied (Tucker and Boyd 1985). After feeding was initiated in March, phosphorus concentrations steadily increased throughout the growing season. This finding corroborates that of Maskey and Boyd (1986), who showed that phosphorus concentrations in ponds are closely related to phosphorus input in feeds and fertilizers. Phosphorus also may be released into the water from the pond mud because of bottom disturbance by aeration (Boyd 1971). Total Kjeldahl nitrogen (TKN) concentrations tended to increase over time reaching higest levels in fall. There was no difference between the samples of the surface and near the bottom ($P>0.05$). Even though there are many nitrogen sources to ponds, including atmospheric nitrogen (N_2), the major source of nitrogen in catfish ponds is protein in feed. During this study, total ammonia nitrogen (TAN), nitrate, and nitrite values varied considerably. Ammonia-nitrogen (NH_3) is much more toxic to fish than ammonium (NH_4^+). The amount of NH_3 form in TAN depends on pH and water temperature (Trussell 1972; Emerson *et al.* 1975). Concentrations as low as 0.1 ㎎/ℓ of NH_3 are thought to adversely affect growth (Boyd 1990). The proportion of NH_3 increases as temperature and pH rise. During the summer, pH values were between 6.6 to 9.0. In this range of pH with temperatures over 30℃, ammonia-nitrogen concentrations in all ponds may have been high enough to affect growth of fish. Highest concentrations of NO_2-N were not high enough to cause methemoglobinemia in channel catfish. Nitrate concentration must exceed 100 ㎎/ℓ before they adversely affect catfish. Concentrations of total suspended solids (TSS), settleable

Table 1. Summary of data collected from the surface and bottom of twenty-five commercial catfish ponds located in central and west-central Alabama, every three months from October 1990 through August 1991

	Variables											
	Temperature (℃)		Dissolved Oxygen (mg/ℓ)		pH		Total Phosphorus (mg PO_4-P/ℓ)		Soluble Reactive P. (mg PO_4-P/ℓ)		BOD_5 (mg/ℓ)	
	surface	bottom	surface	bottom	surface	bottom	surface	bottom	surface	bottom	surface	bottom
Fall												
Mean	14.6	14.1	9.4	8.7	8.7	8.5	0.873	0.867	0.035	0.035	8.3	7.0
Range	10.0~21.7	9.5~22.3	4.3~16.8	4.2~11.7	7.7~9.3	7.7~9.4	0.225~2.540	0.218~2.533	0~0.297	0~0.325	1.3~23.1	2.1~23.4
Winter												
Mean	14.4	13.2	10.5	10.1	8.5	8.4	0.245	0.253	0.005	0.006	9.0	9.0
Range	12.5~16.5	12.0~15.5	7.7~12.5	7.7~12.7	7.7~9.5	7.1~9.2	0.055~0.571	0.035~0.564	0~0.048	0~0.074	1.9~16.8	2.4~21.9
Spring												
Mean	27.6	27.4	6.7	6.4	8.3	8.2	0.208	0.210	0.004	0.004	6.9	6.2
Range	23.5~30.5	23.5~30.0	2.9~9.0	2.6~8.9	8.1~8.6	7.9~8.6	0.080~0.348	0.070~0.371	0~0.042	0~0.042	3.1~14.6	3.2~14.1
Summer												
Mean	31.1	30.0	7.3	5.3	8.1	7.9	0.370	0.347	0.006	0.005	10.8	10.3
Range	28.5~33.0	28.0~32.0	2.6~11.9	0.8~9.8	7.5~8.9	6.6~9.0	0.121~0.713	0.121~0.751	0~0.042	0~0.031	4.8~20.3	4.3~19.5

(continues to next page)

Table 1. Continued

	Variables													
	Settleable Solids (mg/ℓ)		Total Suspended Solids (mg/ℓ)		Volatile Solids (mg/ℓ)		Nitrate (mg NO_3-N/ℓ)		Total Kjeldahl N (mg NH_3-N/ℓ)		Total Ammonia (mg NH_3-N/ℓ)		Nitrite (mg NO_2-N/ℓ)	
	surface	bottom	surface	bottom	surface	bottom	surface	bottom	surface	bottom	surface	bottom	surface	bottom
Fall														
Mean	0.03	0.03	72.5	74.4	17.7	18.2	0.355	0.582	6.09	5.99	2.247	2.255	0.052	0.053
Range	0~0.17	0~0.25	14.0~320.0	16.1~336.7	2.1~85.7	4.2~85.4	0.214~0.710	0.242~1.280	1.98~14.04	1.99~13.49	0.324~5.177	0.361~5.257	0.010~0.280	0.010~0.280
Winter														
Mean	0.05	0.07	78.2	82.8	63.3	67.5	0.493	0.790	3.64	3.73	0.695	0.710	0.029	0.029
Range	0~0.30	0~0.033	22.3~202.1	22.4~202.2	14.4~162.3	16.7~157.8	0.183~4.718	0.240~6.661	0.91~9.19	0.89~9.07	0.065~2.476	0.105~2.462	0.001~0.079	0.002~0.081
Spring														
Mean	0.07	0.04	52.4	52.6	38.5	38.7	1.040	1.054	4.47	4.39	1.079	1.057	0.124	0.126
Range	0~0.40	0~0.20	6.3~111.6	5.2~134.1	2.3~88.4	3.6~97.7	0.233~3.084	0.264~2.980	1.81~10.64	1.87~10.10	0.020~3.429	0.026~3.455	0.001~1.370	0.002~1.410
Summer														
Mean	0.25	0.12	103.0	92.7	87.0	78.5	0.434	0.399	5.67	4.76	1.054	0.772	0.103	0.089
Range	0~1.80	0~0.70	13.6~239.4	17.9~307.6	4.9~236.0	8.8~221.0	0~2.023	0~1.836	3.16~11.26	1.87~8.25	0.050~4.708	0.078~2.136	0.002~0.530	0.002~0.455

solids (SS), and volatile solids (VS) followed similar trend in samples of the surface water and near the bottom. Total suspended solids represent both suspended organic and inorganic particles in the water. Both clay turbidity and plankton contribute to TSS. Settleable solids resulted from particles that rapidly settle from still water. Concentrations of SS were never very high.

In order to show the amount of material that could be released from the ponds in overflow and intentional discharge, all data from Table 1 were averaged for each variable used to compute the amount of each variable that would be discharged in 15,000 m³ of water. This represents draining a 1-hectare pond of 1.5 m average depth (Table 2).

Table 2. Average concentration of each variable in Table 1 and total amount of variables that would be discharged from one hectare of pond of 1.5 m depth

Variable	Average Concentration	Amount per Hectare of Pond
Settleable Solids	0.08 mg/ℓ	1.2 m³
Total Suspended Solid	76.1 mg/ℓ	1142 kg
Volatile Solids	51.2 mg/ℓ	768 kg
Total Phosphorus	0.422 mg/ℓ	6.33 kg
Soluble Reactive P.	0.013 mg/ℓ	0.20 kg
BOD_5	8.4 mg/ℓ	126 kg
Total Ammonia	1.23 mg/ℓ	18.51 kg
Nitrite	0.76 mg/ℓ	1.14 kg
Nitrate	0.635 mg/ℓ	9.53 kg
Total Kjeldahl Nitrogen	4.84 mg/ℓ	72.6 kg

Data on concentrations of water quality variables in three streams in central and west-central Alabama are compared with annual average for the 25 commercial catfish ponds in Table 3. This comparison clearly shows that catfish pond effluents have much higher average concentrations of nitrogen and phosphorus than streams. Although BOD values for streams were not available. The BOD of catfish pond water was often much greater than that expected in unpolluted streams (Boyd 1978).

These data show that catfish pond effluents could lead to nutrient and organic matter enrichment of receiving waters. Also, solids discharged from ponds could cause sediment problems in streams. However, the actual impact of catfish pond effluents cannot be determined simply from concentrations of water quality variables. The volume of water discharged from ponds relative to receiving stream flow must be considered. The problem would be much more acute where a large number of ponds discharged into a small stream than where a few ponds discharged into a large stream.

A number of techniques for dealing with the effluent problem are being discussed within the catfish industry. These include settling ponds and created wetlands for treating effluents and water reuse systems for preventing effluents. However, there has been inadequate research and practical application of these techniques to prove their usefulness. For the present, use of good pond management techniques to maintain water quality within ponds, e. g., use of high quality feeds, conservative feeding practices, moderate stocking rates, aeration, and water circulation, and operation of ponds to minimize discharge can reduce any possible impact of effluents in receiving waters.

Table 3. Average water quality variables from selected streams, based on 6 years' record (1984~1989), and 25 commercial ponds in central and west-central Alabama

Variables	Stream No.			Commercial Ponds
	35	41	43*	
Temp	23.6^{a}	26.9^{b}	20.9^{c}	21.6^{c}
DO	6.6^{a}	7.7^{b}	7.4^{b}	8.1^{c}
pH	7.4^{a}	7.4^{a}	6.9^{a}	8.3^{b}
NO_3	0.11^{a}	0.18^{b}	0.09^{a}	0.64^{b}
NO_2	0.01^{a}	$**^{a}$	ND^{a}	0.08^{b}
NH_4	0.06^{a}	0.01^{b}	0.07^{a}	1.23^{c}
TKN	0.46^{a}	0.40^{a}	0.58^{b}	4.84^{c}
TP	0.04^{a}	0.01^{b}	0.08^{c}	0.42^{d}
OP	0.03^{a}	0.02^{a}	0.03^{a}	0.01^{b}
TSS	46^{a}	22^{b}	21^{b}	76^{c}

Values having the same superscript are not significantly different at $P>0.05$, (horizontal comparison only).

Based on t-test among the values (SAS 1986).

Source: Moore and Richter (1985 and 1986), and Moore (1987, 1988, 1989, and 1990).

*: 1985 to 1989

**: <0.002

ND: Not Detected

ABSTRACT

Studies related to water quality in catfish ponds were conducted on commercial catfish production ponds and compared with its receiving streams' water quality in central and west-central Alabama. The ponds were stocked with 10,000 fish/ha. The ponds were aerated nightly (0000—0600 hrs). Fish were fed to satiation at about the same time, six-days a week. In order to assess the pollutional strength of effluents from commercial channel catfish ponds, water samples were collected during each calender season from fall 1990 through summer 1991, and selected water quality variables were monitored. Mean values for water temperature, dissolved oxygen concentration, pH, settleable solids, total suspended soilds,

volatile solids, total phosphorus, soluble reactive phosphate, biochemical oxygen demand, total ammonia nitrogen, nitrite, nitrate, and total Kjeldahl nitrogen were basically the same ($P>0.05$) between samples taken from the surface and near the bottom.

Concentrations of most water quality variables of catfish ponds were higher than those of receiving streams, and especially it had much higher average concentrations of nitrogen and phosphorus than streams.

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