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EFFECTS OF MECHANICAL MIXING IN RESERVOIRS ON SEASONAL AND ANNUAL GROWTH RATES OF FISHES

by

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ABSTRACT

Stratification of lakes and reservoirs results in poor water quality and reduced fish habitat in the hypolimnion. Lake Arbuckle, Oklahoma was mechanically mixed in 1977 in an attempt to destratify the reservoir and to improve environmental conditions for fish. Fish were taken in 1976 and 1977 using gill nets and seasonal and annual growth rates were measured from scales and spines. Mixing of the reservoir in 1977 increased the average amount of available fish habitat. Seasonal growth rates of gizzard shad and channel catfish, bottom feeding fish, were greater during the destratified period when more of the bottom area was available for feeding. White crappie and white bass which are pelagic feeders did not appear to be as adversely affected by the loss of bottom habitat. Mechanical mixing increased the amount of available fish habitat in late summer which probably benefitted growth, but the best growth occurred when available fish habitat was expanded in early summer. In order to maximize growth, mixing should begin in early May with the objective of preventing vertical stratification.

INTRODUCTION

This report examines seasonal and annual growth of five species of fish in Lake-of-the-Arbuckles (hereinafter referred to as Lake Arbuckle), Oklahoma in 1976-77 and compares these rates with those in 1973-75 (Summerfelt and Gebhart 1976). This study was undertaken to describe the response in terms of growth of the fish community to engineering efforts to artificially destratify the reservoir in 1973, 1974, 1975, and 1977 as a means of improvement of water quality for municipal and industrial usage.

Growth was chosen as the measure of the impact of destratification on the fish community because it is highly plastic and influenced by food, temperature, space, dissolved oxygen (DO) and other factors (Weatherly 1962). Aeration or artificial destratification affects most, if not all, of these aforementioned factors and thus the production process (Toetz et al. 1972). Primary production (photosynthesis) and intermediate production (by invertebrates) provide food for fish. Factors which affect these processes strongly influence the ultimate yield of fishes and a short-term study of fish growth may serve as an overall indication of environmental quality (Gunning and LaNasa 1973).

Growth is one of two components used in computation of fish production (P), $P = G\bar{B}$, where G equals the instantaneous growth coefficient and $\bar{B}$ equals the average population biomass (Chapman 1971). The average population biomass is very difficult to obtain in large reservoirs, because an estimate of the number and size of fish in the population must be made for at least two points in time. Thus, fish growth appears to be the most convenient aspect of the production process to examine for effects of an environmental perturbation upon the fish community.

Poor water quality during stratification (high ammonia, hydrogen sulfide, carbon dioxide and low DO) and its concomitant effects on production of benthic invertebrates are likely to slow growth of fishes. Laboratory experiments, which simulate the conditions found in stratified lakes, show diminished growth at low DO levels and high temperatures. Stewart et al. (1967) reported that growth of juvenile largemouth bass (*Micropterus salmoides*) was sharply reduced by DO levels that were below air saturation or were fluctuating significantly . Growth of channel catfish (*Ictalurus punctatus*) was similarly reduced by low DO levels (Andrews et al. 1973) and high temperatures of 30 to 34 C (Andrews and Stickney 1972).

Hypolimnetic anoxia, which develops as a result of stratification, restricts fish from continuous occupancy of the hypolimnion of lakes and reservoirs (Bardach 1955; Borges 1950; Dendy 1945; Fast 1971, Gebhart and Summerfelt 1975 and 1976; Grinstead 1969; Hile and Juday 1941, Mayhew 1963; Sprugel 1951; Summerfelt and Hover 1972; Ziebell 1969). Normal summer temperatures at the surface can exceed the optimum range for warmwater fishes as ascertained from laboratory and field studies of preferred temperatures (Ferguson 1958). Stratification concentrates even warmwater fishes in a narrow transitional stratum between the anoxic hypolimnion and the thermally oppressive epilimnion. This compression effect of stratification may be lethal to coldwater fishes in certain marginal lakes (Colby and Brooke 1969).

Numerous studies have failed to clarify the relationships between stratification and growth of fishes. Mayhew (1963) noted that, at the time of severe stratification and hypolimnetic stagnation, a majority of bluegill (*Lepomis macrochirus*) scales developed false annuli and that growth was greatly retarded in relation to the prestratification rate and he suggested that stratification is a primary factor controlling growth of bluegill. Johnson (1966) measured growth of fish before and after destratification of a lake used to rear coho salmon (Oncorhynchus kisutch). The average growth decreased slightly after destratification, probably due to an increase in survival from 12.9% before to 42.1% after destratification. This improved survival increased total production by over 300%.

OBJECTIVES

The original objectives of this project (as stated in the proposal) were:

1. Evaluate seasonal (summer vs winter) and annual growth of five species of fish in Lake Arbuckle, a man-made lake in south-central Oklahoma, in 1976 and 1977.
2. Compare seasonal and annual growth for corresponding intervals in 1973-75, when the lake was stratified, to 1976, when Dr. James Garton will employ an axial flow pump to maintain the reservoir in a destratified condition.

The objectives were accomplished with only minor changes. We described the growth of white bass (Morone chrysops) instead of black bullhead (Ictalurus melas) because of the reduction of black bullhead and increase of white bass in the collections. The axial flow pump was not installed until the summer of 1977; therefore, the 1976 data will serve as a baseline for fish growth when the reservoir was not artificially mixed and growth data for the spring and fall of 1977 will serve as a measure of growth in relation to mechanical mixing.

DESCRIPTION OF THE RESERVOIR

Lake Arbuckle is located in the Arbuckle Mountains in south-central Oklahoma on Rock Creek in Murray County, Oklahoma (Figure 1). This is a region of low rolling hills which creates a relatively deep, steep sided lake: surface area 951 hectares, capacity 89,300,000 m^3 (8930 ha/m), average depth 9.39 m, and maximum depth of 27.5 m. The watershed receives an annual precipitation of about 96 cm and the average length frost-free period is 218 days. The lake is usually thermally stratified from mid-May through September with a thermocline established at a depth of approximately 7 m. Duffer and Harlin (1971) present temperature and DO profiles which indicate a thermocline at 6 m on 30 July 1969 with anoxic conditions present below 7 m. A thermocline existed at 18 m on 15 October, 1969 with DO declining below that depth to 1.5 mg/l DO at 24 m. A similar pattern of stratification was evident in Lake Arbuckle in 1968.

METHODS AND MATERIALS

The growth of fish was related to destratification of the reservoir by artificial mixing. Since no attempt was made to artificially mix the lake in 1976, data for 1976 will serve as a measure of growth in a normal year. During the summer of 1977, an attempt was made to destratify the lake using axial flow pumps similar to one described by Quintero and Garton (1973). The destratification device consisted of 16 pumps, each with a 1.5 horsepower electric motor turning a 1.8 m diameter propeller blade, arranged in an open centered square with a pumping capacity of 1590 m^3/minute. The device was operated from 1 July to 24 September.

Fish were collected at four sites. Sites 2, 3, 4 and 5 were close to

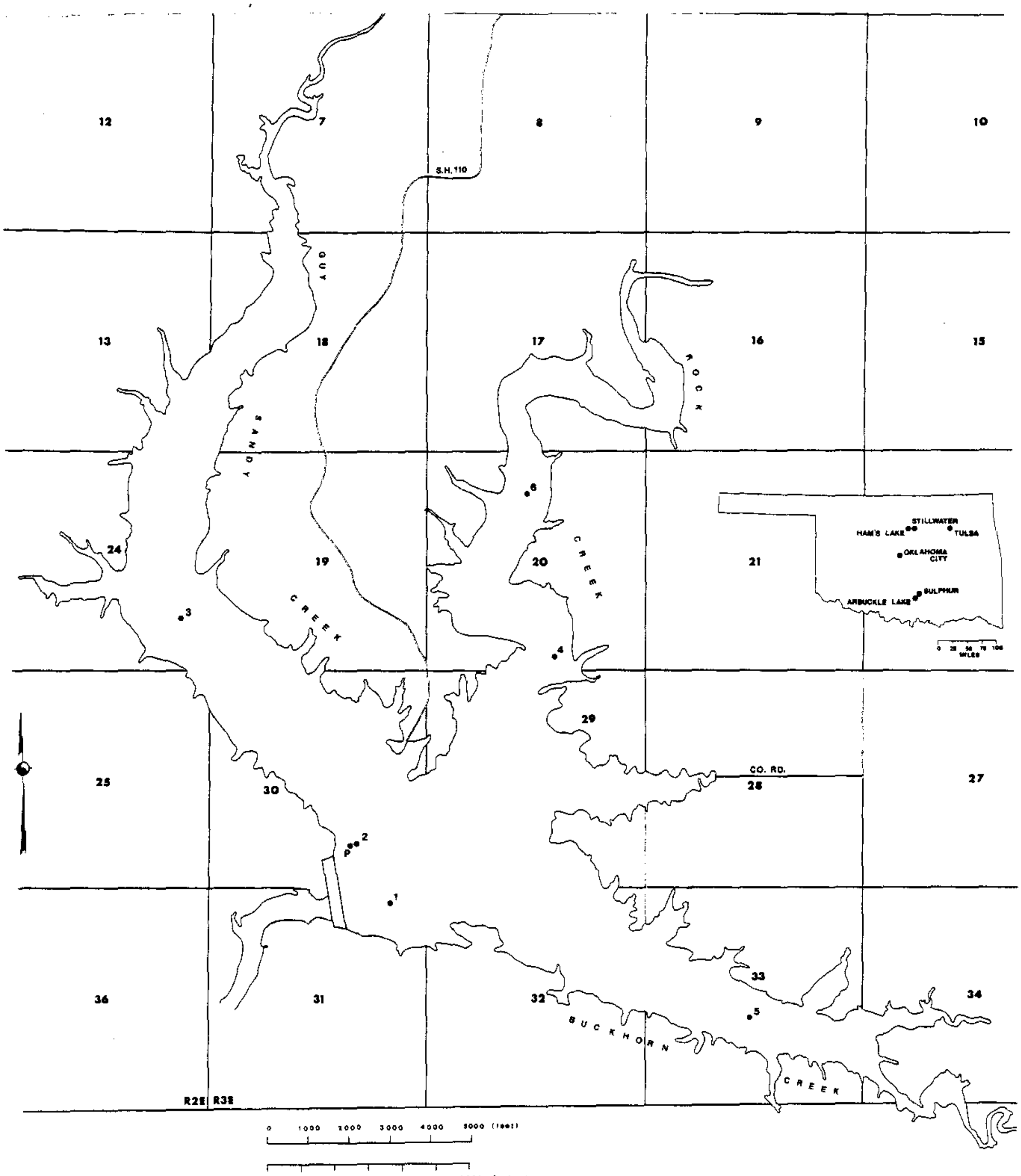

Figure 1. Lake Arbuckle, showing fish collection sites.

the dam, in the Guy Sandy Creek Arm, in the Rock Creek Arm, and in the Buckhorn Creek Arm, respectively. Respective distances of the sites from the mixing device were 200, 2067, 2250 and 3033 m. Site 2 was located near the mixing device to measure any local effects on growth in the event of partial destratification.

Fish were sampled by use of experimental gill nets, 3.05 m deep by 45.73 m long, divided into six 7.62 m panels with individual panel square mesh sizes of 1.27 cm, 2.54 cm, 3.81 cm, 6.35 cm, and 7.62 cm. Nets were fished in a horizontal position on the bottom at depths of 0-5 m, 5-10 m, 10-15 m, and 15-20 m. The nets were set at the specified intervals with the aid of a recording echosounder. These depth intervals were chosen to sample the epilimnion, metalimnion, and hypolimnion. One series of nets (one 45.73 m net fished at each of the four depth contours) was set at each of sites 3, 4 and 5 each week. Three series of nets were set at site 2 each week. Therefore, one-half of the sampling effort took place at the mixing device. Nets were fished for approximately 24-hour intervals and catch was adjusted to express number of fish per 24 hours.

In 1976, fish were collected from 10 May to 8 July and from 20 September to 1 October. In 1977 fish were collected from 9-20 May and from 18-29 September.

Fish were weighed and measured and scales were taken from scaled fish, and spines were taken from the catfish. The scales and spines were examined to determine the age of the fish and to back-calculate growth for previous years of life from use of the body-scale relationship as described by Tesch (1971). The body-scale relationships were established using a step-wise 5th degree polynomial regression of length on total scale radius. The step ("degree") which gave the best fit, i.e., least deviation of the calculated lengths from the observed, was used to back-calculate the growth. The fifth degree polynomial equation was:

$$Y = \hat{\alpha} + \hat{\beta}_1 (X) + \hat{\beta}_2[(X^2)(10^{-3})] + \hat{\beta}_3[(X^3)(10^{-5})] + \hat{\beta}_4[(X^4)(10^{-7})] + \hat{\beta}_5[(X^5)(10^{-9})]$$

where: X = focus to annulus measurement,

Y = estimated total length at age X,

$\hat{\alpha}$ = the Y axis intercept and

$\hat{\beta}_{1-5}$ = the stepwise regression coefficients

Growth was calculated for gizzard shad (Dorosoma cepedianum), white crappie (Pomoxis annularis), freshwater drum (Aplodinotus grunniens), channel catfish, and white bass. Annual growth was calculated for fish taken in both May 1976 and May 1977. The two calculations gave slightly different estimates of growth, therefore, only the 1977 data were used to calculate annual growth since it included data for 1976 as well as earlier years. Annual growth increments were described for each species and year of life and the significance of difference among these years was tested statistically by an analysis of variance procedure. If the analysis of variance test showed a significant difference among years, then each year was tested against all other years using a least significant difference test (Steel and Torrie 1960:106, 114). If the analysis of variance test did not show a significant difference among years then according to accepted statistical procedure the least significant difference test or t-test cannot be applied to test the differences (Steel and Torrie 1960:107), and it is assumed that there is no significant difference between growth in any of the years.

Instantaneous growth rates were calculated for the stratified summer interval and for the destratified overwintering period for all age groups that were adequately represented in the sample. The instantaneous growth coefficient, G, was measured using the equation:

$$G = \frac{(\log_e \bar{w}_2 - \log_2 \bar{w}_1)}{\Delta t}$$

where $\bar{w}_1$ and $\bar{w}_2$ = mean weights of fish at time t_1 and t_2 (Chapman 1968:187). It should be noted that the G value is the mean population growth rate and not a mean growth rate of individual fish. The latter could not be obtained since it would require recapture of marked fish; the population growth is generally lower than the individual fish growth rate for fish older than age 1 or 2 (Ricker 1971:129). These G values were then examined in relation to conditions of stratification. Dissolved oxygen was related to fish growth. Statification of DO develops shortly after thermal stratification and closely follows the extent of thermal stratification. The literature survey by Doudoroff and Shumway (1970) indicates that fish generally avoid water containing less than 2 mg/l DO. The previous study on depth distribution of fish in Lake Arbuckle (Gebhart and Summerfelt 1976) indicated that most fish were limited in their distribution by the anoxic hypolimnion. Therefore, we used the 2 mg/l DO isopleth (the lake contour at which 2 mg/l DO was present) as the lower level of suitable fish habitat; generally, the water became anoxic within two meters below the 2 mg/l DO isopleth. The volume of available fish habitat (AFH) was calculated weekly for both years. An average volume of AFH was then calculated for each growth period (stratified and destratified).

RESULTS

Available Habitat Analysis

Available fish habitat (AFH) was subtantially reduced in Lake Arbuckle during summer stratification in both 1976 and 1977, as observed in 1973-75 (Table 1). Available fish habitat was reduced to as low as 55.6% in 1976 and 60.0% in 1977. The average AFH was substantially higher in 1977 when the pump was operating than in 1976. Lake Arbuckle stratified later than normal in 1976 which increased the average AFH in relation to the other years. The pump was started on 1 July 1977, and increased the AFH by August. Of the five years of study, the AFH was greatest in 1974 followed by 1977, 1973, 1976 and 1975.

Species Composition

The total catch of fish per effort (c/f) was fairly constant over the four sampling periods except for the expanded summer collection in 1976 (Table 2) when c/f was approximately double that of any of the other three collections. This was partially due to the existence of an oxygenated hypolimnion for much of the summer, which allowed the fish to move freely and be captured at all depths. The c/f did decline in June of 1976 when AFH declined (Table 1) and fish movement was restricted. After the substantial decrease in c/f for all species from summer to fall of 1976, c/f of most species either increased, or stayed about the same over the next two periods.

The c/f for channel catfish and white bass increased while the c/f of black bullheads decreased markedly in 1977. The five species selected for

Table 1. Percent of available fish habitat in Lake Arbuckle during the stratified period, 1973-77.

1973		1974		1975		1976		1977	
Day/ month	% Habitat	Day/ month	% Habitat	Day/ month	% Habitat	Day/ month	% Habitat	Day/ month	% Habitat
14 May	100.0			12 May	98.0	10 May	99.0	9 May	94.0
21 May	97.0	20 May	90.3	19 May	92.0	17 May	99.0	16 May	83.8
28 May	91.0	27 May	85.0	26 May	87.0	24 May	97.8	23 May	83.6
4 June	88.6	3 June	81.0	2 June	70.0	31 May	94.2	30 May	83.0
11 June	84.1	10 June	81.0	9 June	70.0	7 June	90.0	6 June	79.0
18 June	75.7	17 June	75.0	16 June	75.0	14 June	76.0	13 June	74.0
25 June	69.8	24 June	70.0	23 June	71.0	21 June	58.6	20 June	68.9
2 July	65.0	1 July	70.0	30 June	57.0	28 June	68.1	27 June	65.0
9 July	58.3	8 July	67.0	7 July	49.0	5 July	63.7	4 July	65.0
16 July	53.8	15 July	68.0	14 July	47.0	12 Jul7	55.6	11 July	65.0
23 July	52.9	22 July	61.0	21 July	50.0	19 July	56.3	18 July	64.1
30 July	56.7	29 July	62.0	28 July	47.0	26 July	58.0	25 July	60.0
6 Aug.	60.6	5 Aug.	74.0	4 Aug.	44.0	2 Aug.	58.0	1 Aug.	66.0
13 Aug.	57.0	12 Aug.	83.0	11 Aug.	41.0	9 Aug.	58.0	8 Aug.	70.8
20 Aug.	52.5	19 Aug.	83.0	18 Aug.	53.0	16 Aug.	59.2	15 Aug.	72.0
27 Aug.	54.4	26 Aug.	86.1	25 Aug.	62.1	23 Aug.	64.0	22 Aug.	80.0
3 Sept.	61.2	2 Sept.	89.3	1 Sept.	71.3	30 Aug.	64.2	29 Aug.	88.0
10 Sept.	67.2	9 Sept.	92.2	8 Sept.	80.5	6 Sept.	68.3	5 Sept.	91.0
17 Sept.	73.2			15 Sept.	89.6	13 Sept.	72.0	12 Sept.	83.2
24 Sept.	79.0			22 Sept.	99.0	20 Sept.	78.5	19 Sept.	95.0
1 Oct.	85.0								
8 Oct.	90.6								
15 Oct.	96.2								
Average	72.6		77.5		67.7		71.9		76.6

Table 2. Numbers, percent of total catch, and catch per gill net day (c/f) of 13 species of fishes in Lake Arbuckle, 1976 and 1977.

Species	10 May to 8 July 1976			20 Sept. to 1 Oct. 1976			9 to 20 May 1977			18 to 29 Sept. 1977		
	No.	%	c/f[a]	No.	%	c/f	No.	%	c/f	No.	%	c/f
Gizzard shad	1790	39.7	8.5	118	26.9	2.5	231	41.8	4.8	201	39.7	4.2
White crappie	1030	22.8	4.9	174	39.6	3.6	77	14.0	1.6	86	17.0	1.8
Freshwater drum	476	10.6	2.3	38	8.7	0.8	90	16.3	1.9	48	9.5	1.0
Channel catfish	160	3.6	0.8	27	6.2	0.6	40	7.2	0.8	83	16.4	1.7
White bass	393	8.7	1.9	26	5.9	0.5	41	7.4	0.9	52	10.3	1.1
Black bullhead	132	2.9	0.6	19	4.3	0.4	10	1.8	0.2	4	0.8	0.1
Carp	20	0.4	0.1	3	0.7	0.1	3	0.5	0.1	15	3.0	0.3
Bluegill	310	6.9	1.5	19	4.3	0.4	44	8.0	0.9	9	1.8	0.2
Warmouth	62	1.4	0.3	1	0.2	0.0	2	0.4	0.0	2	0.4	0.0
Flathead catfish	50	1.1	0.2	3	0.7	0.1	3	0.5	0.1	1	0.2	0.0
Largemouth bass	10	0.2	0.1	0	0.0	0.0	6	1.1	0.1	2	0.4	0.0
River carpsucker	37	0.8	0.2	0	0.0	0.0	2	0.4	0.0	1	0.2	0.0
Walleye	37	0.8	0.2	11	2.5	0.2	3	0.5	0.1	2	0.4	0.0
Total	4507	99.9	21.5	439	100.0	9.2	552	99.9	11.5	506	100.1	10.5

[a]Catch per unit of effort: the average number of fish taken in one gill net fished for 24 hours.

study were gizzard shad, white crappie, freshwater drum, channel catfish, and white bass which together accounted for at least 85% of the catch in all of the collections. The growth data will be presented by species since growth varies among species and species may vary in their response to the same environmental factors.

Gizzard Shad

Annual Growth Rates

First year growth (from initial scale formation to first annulus) of gizzard shad was computed for 1971-75 (Table 3). No age-1 fish were collected in the gill nets in 1977 so first year growth could not be backcalculated for 1976. The analysis of variance (AOV) indicated a significant difference ($P<.05$) among the first-year growth increments. The least significant difference (LSD) test indicated that 1975 growth was significantly greater than growth in the other four years (Table 4). Growth in 1973 was also significantly greater than in 1971.

Second-year growth differed significantly among years according to the AOV test. The LSD test showed that second-year growth in 1974 and 1975 was significantly larger than in 1973 and 1976 (Table 4). Third-year growth differed significantly, with that in 1976 being larger than that in 1974 and 1975 (Table 5). Fourth-year growth also differed significantly, with that in 1974 being higher than that in 1976 (Table 5). The two fifth-year growth increments were not significantly different.

Growth was not consistantly better in any year for all ages. According to the available habitat analysis, growth should have been best in 1974, followed by 1973, 1976, and 1975 (Table 1). Growth rates were highest in

Table 3. Mean annual growth increments (mm) (± 95% confidence interval) for gizzard shad in Lake Arbuckle, 1971-76.

Year of growth	Age 1	2	3	4	5	6
1971	134.8±4.1 (8)[a]					
1972	137.1±2.0 (23)	66.7±7.5 (8)				
1973	140.7±2.2 (24)	62.3±6.4 (23)	37.6±8.0 (8)			
1974	137.9±1.8 (30)	73.1±5.1 (24)	35.6±4.4 (23)	26.2±4.1 (8)		
1975	152.5±3.4 (34)	69.9±4.0 (30)	34.3±4.0 (24)	21.0±2.2 (23)	16.5±5.0 (8)	
1976		61.6±3.4 (34)	43.0±3.0 (30)	19.7±3.1 (24)	14.2±2.3 (23)	11.3±3.8 (8)

[a]Value in ( ) indicates number of fish.

Table 4. Annual growth increments of gizzard shad for first and second years tested for significant difference (0.05 level) by the analysis of variance test, 1971-76. [Differences in growth increments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	First year growth				
	1971	1972	1973	1974	1975
1971	-				
1972	2.3	-			
1973	5.9*	3.6	-		
1974	3.1	0.8	2.8	-	
1975	17.7*	15.4*	11.8*	14.6*	-

Year of growth	Second year growth				
	1972	1973	1974	1975	1976
1972	-				
1973	4.4	-			
1974	6.4	10.8*	-		
1975	3.2	7.6*	3.2	-	
1976	5.1	0.7	11.5*	8.3*	-

Table 5. Annual growth increments of gizzard shad for third and fourth years tested for significant difference (0.05 level) by the analysis of variance test, 1973-76. [Differences in growth increments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	Third year growth			
	1973	1974	1975	1976
1973	-			
1974	2.0	-		
1975	3.3	1.3	-	
1976	5.4	7.4*	8.7*	-
Year of growth		Fourth year growth		
		1974	1975	1976
1974		-		
1975		5.2	-	
1976		6.5*	1.3	-

1974 in two of the four age-groups examined, with those in 1975 being greatest in two of five groups and those in 1976 larger in one group.

Seasonal Growth Rates

Gizzard shad of age 3 gained most of their weight during the destratified overwinter period and even had faster growth during the longer destratified period in all but one case (Table 6). The best growth during the stratified periods was in 1976, which was substantially better than any of the other years. An unusually large amount of AFH in May and early June of 1976 may partially explain the high growth rate since fish growth in general seems to be fastest in late spring and early summer. The most AFH occurred in 1974, which had the second highest growth rates.

Gizzard shad of age 4 also gained most of their weight during the destratified period in all but one case (Table 7). The best growth rate for the stratified period occurred in 1974 when AFH was the highest.

White Crappie

Annual Growth Rates

The largest annual growth increment for age-1 white crappie occurred in 1976 (Table 8). According to the AOV test, first-year growth increments differed significantly among years. The LSD test revealed that growth in 1976 was significantly larger than in 1974 or 1975 (Table 9). Growth during the second year was significantly larger in 1976 than in 1974 or 1974 (Table 9). In the only comparison of third-year growth, growth in 1976 was statistically larger than in 1975. The fast growth rate of crappie in 1976 could be due to the high AFH in early summer.

Table 6. Comparison of growth rates (G) and mean weight gain (g) for gizzard shad for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 3				
5-23-73	151						
		149.0	-0.17	-2.0			72.6
10-19-73	86						
		221.5			1.58	31.1	99.1
5-29-74	6 72						
		105.5	0.98	8.7			77.5
9-11-74	15						
		252.0			1.20	31.4	99.3
5-21-75	32 14						
		128.0	0.71	7.2			67.7
9-24-75	34						
		236.5			2.96	83.8	99.8
5-19-76	12 18						
		130.0	1.25	20.9			71.9
9-25-76	7						
		231.0			1.27	47.4	97.3
5-14-77	55 34						
		132.0	0.45	9.4			76.6
9-23-77	52						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 7. Comparison of growth rates (G) and mean weight gain (g) for gizzard shad for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 4				
5-23-73	60						
		149.0	1.33	29.2			72.6
10-19-73	28						
		221.5			0.53	20.5	99.1
5-29-74	18 6						
		105.5	1.40	16.8			77.5
9-11-74	4						
		252.0			1.69	65.1	99.3
5-21-75	110 32						
		128.0	1.13	18.8			67.7
9-24-75	7						
		236.5			1.24	47.6	99.8
5-19-76	56 12						
		130.0	-0.03	-0.6			71.9
9-25-76	9						
		231.0			1.61	74.8	97.3
5-14-77	44 55						
		132.0	0.52	13.2			76.6
9-23-77	41						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 8. Mean annual growth increments (mm) (± 95% confidence interval) for white crappie in Lake Arbuckle, 1973-76.

Year of growth	Age 1	2	3	4
1973	130.6± 0.0 (1)[a]			
1974	121.8± 1.4 (53)	50.3± 0.0 (1)		
1975	119.3± 3.1 (16)	52.2± 2.6 (53)	32.2±0.0 (1)	
1976	137.7±25.6 (2)	104.0± 7.9 (16)	66.5±2.5 (53)	28.2±0.0 (1)

[a]Value in ( ) indicates number of fish.

Table 9. Differences in annual growth increments of white crappie for first, second, and third years tested for significant difference (0.05 level) by the analysis of variance test, 1973-76. [Differences in growth increments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	First year growth 1973	1974	1975	1976
1973	-			
1974	8.8	-		
1975	11.3	2.5	-	
1976	7.1	15.9*	18.4*	-

Year of growth	Second year growth 1974	1975	1976
1974	-		
1975	1.9	-	
1976	53.7*	51.8*	-

Year of growth	Third year growth 1975	1976
1975	-	
1976	34.3*	-

Seasonal Growth Rates

Age-1 white crappie gained more weight during the destratified period, but in most years growth was substantially higher in the stratified summer period (Table 10). The greatest growth for the stratified period occurred in 1976 when AFH was above average in early summer. The second greatest growth occurred in 1974 when average AFH was highest, and the lowest growth rate occurred in 1975 when the average AFH was lowest.

For age-2 white crappie, the mean weight gains and growth rates were higher on the average in the stratified period than the destratified interval (Table 11). As for age-1 crappie, the growth rate in the stratified period was highest in 1976, second highest in 1974 and lowest in 1975. The growth rate in 1977, when mechanical mixing took place, was about average even though AFH was substantially increased in late summer.

Freshwater Drum

Annual Growth Rates

The mean annual growth increment of age-1 drum was fairly constant, ranging from 169.2 to 189.8 mm (Table 12). The growth in 1975, when AFH was lowest, was significantly lower than 1972, 1973, and 1974 (Table 13). The second-year growth increments consistantly decreased from 1973 to 1976. Growth in 1973 was significantly higher than the other three years while growth in 1974 was significantly larger than 1976 growth (Table 13). Third- or fourth-year growth increments did not differ significantly between years.

Table 10. Comparison of growth rates (G) and mean weight gain (g) for white crappie for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 1				
6-12-73	2						
		63.0	6.30	21.7			72.6
8-14-73	4						
		241.5			0.90	19.7	99.1
5-29-74	15 48						
		105.5	8.25	42.8			77.5
9-11-74	54						
		252.0			4.39	149.0	99.3
5-21-75	24 114						
		128.0	0.12	0.8			67.7
9-24-75	53						
		236.5			1.35	19.4	99.8
5-19-76	202 2						
		130.0	8.32	58.5			71.9
9-25-76	42						
		231.0			1.20	51.8	97.3
5-14-77	17 2						
		132.0	4.30	22.2			76.6
9-23-77	6						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 11. Comparison of growth rates (G) and mean weight gain (g) for white crappie for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 2				
5-23-73	47						
		149.0	1.42	30.2			72.6
10-19-73	3						
		242.0			2.06	102.0	99.1
6-18-74	2						
5-29-74	8						
		105.5	6.37	142.3			77.5
9-11-74	8						
		252.0			0.64	51.7	99.3
5-21-75	3 24						
		128.0	-0.90	-24.4			67.7
9-24-75	32						
		236.5			-0.82	-35.0	99.8
5-19-76	13 202						
		130.0	8.57	122.2			71.9
9-25-76	111						
		231.0			0.03	1.3	97.3
5-14-77	53 17						
		132.0	3.93	95.3			76.6
9-23-77	30						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 12. Mean annual growth increments (mm) (± 95% confidence interval) for freshwater drum in Lake Arbuckle, 1972-76.

Year of growth	Age 1	2	3	4	5
1972	184.7±17.3 (6)[a]				
1973	189.8± 8.8 (13)	55.9±18.2 (6)			
1974	187.9± 5.0 (33)	42.8± 6.7 (13)	20.2±8.0 (6)		
1975	169.2± 3.6 (34)	35.6± 3.6 (33)	23.7±7.6 (13)	12.8±3.0 (6)	
1976	178.3± 0.0 (1)	34.0± 3.0 (34)	19.8±2.1 (33)	13.3±3.2 (13)	9.4±2.0 (6)

[a]Value in ( ) indicates number of fish.

Table 13. Differences in annual growth increments of freshwater drum for first and second years tested for significant difference (0.05 level) by the analysis of variance test, 1972-76. [Differences in growth incrments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	First year growth				
	1972	1973	1974	1975	1976
1972	-				
1973	5.1	-			
1974	3.2	1.9	-		
1975	15.5*	20.6*	18.7*	-	
1976	6.4	11.5	9.6	9.1	-

Year of growth	Second year growth			
	1973	1974	1975	1976
1973	-			
1974	13.1*	-		
1975	20.3*	7.2	-	
1976	21.9*	8.8*	1.6	-

Seasonal Growth Rates

The average growth rate and weight gain was substantially higher in the stratified summer period for age-2 freshwater drum (Table 14). The highest growth rate for the stratified period occurred in 1976, the year of high AFH during the early summer. The two years of high average AFH due to mechanical mixing, 1974 and 1977, did not have a correspondingly high growth rate. The high average AFH in both years was mainly a result of an increase in habitat in August when mixing began to alter the stratification pattern. The expansion in habitat in August does not appear to improve growth as significantly as an expansion in habitat in the early summer.

The average growth of age-3 drum was greater in the stratified than the destratified period (Table 15). The greatest stratified growth occurred in 1976 which follows the pattern of other age groups of drum. The second and third highest growth rates occurred in 1977 and 1974, the years of highest average AFH.

Channel Catfish

Annual Growth Rates

The mean annual growth increments for age-1 channel catfish varied from 155.6 to 171.6 mm, but there was no significant difference among years according to the AOV test (Table 16). The growth increments for age-2 channel catfish ranged from 99.2 to 118.3 mm, but again there was no statistically significant difference among years. Growth was surprizingly constant from 1973 to 1975, but decreased in 1976.

Growth increments for age-3 channel catfish differed significantly among years. Growth in 1976 was larger than in 1973 or 1975 according to

Table 14. Comparison of growth rates (G) and mean weight gain (g) for freshwater drum for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 2				
5-23-73	26						
		149.0	-1.29	-34.7			72.6
10-19-73	7						
		221.5			1.44	61.1	99.1
5-29-74	41 1						
		105.5	0.75	14.7			77.5
9-11-74	13						
		252.0			0.71	38.2	99.3
5-21-75	64 20						
		128.0	5.26	99.0			67.7
9-24-75	12						
		236.5			-0.01	-0.7	99.8
5-19-76	50 95						
		130.0	7.56	118.3			71.9
9-25-76	22						
		231.0			-0.53	-21.9	97.3
5-14-77	34 34						
		132.0	0.89	10.8			76.6
9-23-77	22						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 15. Comparison of growth rates (G) and mean weight gain (g) for freshwater drum for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period $G(10^{-3})$	Stratified period g	Destratified period $G(10^{-3})$	Destratified period g	Available habitat (%)
			Age group 3				
5-23-73	35						
		149.0	-1.52	-59.9			72.6
10-19-73	12						
		221.5			0.65	36.6	99.1
5-29-74	9 41						
		105.5	0.63	15.4			77.5
9-11-74	10						
		252.0			Insufficient data		99.3
5-21-75	0 64						
		128.0	0.16	4.8			67.7
9-24-75	7						
		236.5			Insufficient data		99.8
5-19-76	0 50						
		130.0	1.53	44.3			71.9
9-25-76	7						
		231.0			-0.52	-28.0	97.3
5-14-77	14 34						
		132.0	0.77	17.9			76.6
9-23-77	14						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 16. Mean annual growth increments (mm) (± 95% confidence interval) for channel catfish in Lake Arbuckle, 1971-76.

Year of growth	Age 1	2	3	4	5	6
1971	170.4±14.7 (8)[a]					
1972	158.1±19.5 (5)	113.2±14.7 (8)				
1973	161.7±12.8 (10)	118.3±18.8 (5)	72.8±11.9 (8)			
1974	155.6±15.7 (6)	118.1±15.2 (10)	88.2±11.6 (5)	60.2± 8.7 (8)		
1975	171.6±10.1 (14)	118.3±10.4 (6)	72.9± 9.0 (10)	60.2±10.5 (5)	55.1± 9.4 (8)	
1976		99.2± 8.8 (14)	95.0±16.2 (6)	63.0± 9.6 (10)	47.3±12.6 (5)	63.4±12.7 (8)

[a]Value in ( ) indicates number of fish.

the LSD test (Table 17). Growth increments for age-4 or -5 catfish did not differ significantly between years.

Seasonal Growth Rates

The majority of the weight gained by age-3 channel catfish was during the destratified period and even the average growth rate was higher in the destratified period (Table 18). The fastest growth rate for the summer stratified period was in 1977 when the reservoir was being mechanically mixed. The next fastest growth occurred in 1974 when average AFH was the greatest. The poorest growth occurred in 1975, which was the year of lowest AFH.

White Bass

Annual Growth Rates

The annual growth rates for age-1 white bass were significantly different between years, varying from 262.7 to 294.5 mm (Table 19). According to the LSD test, growth in 1976 was significantly higher than in 1974 or 1975 (Table 20). Growth in 1973 was also significantly higher than growth in 1975.

Age-2 growth did not differ significantly among years but growth of age-3 white bass was significantly larger in 1976 than in 1975 (Table 20).

Seasonal Growth Rates

Seasonal growth rates for white bass were only estimated for 1975-77, since the population only recently expanded to a density which allowed for adequate sampling. The average weight gain and growth rates were sub-

Table 17. Differences in annual growth increments of channel catfish for third year tested for significant difference (0.05 level) by the analysis of variance test, 1973-76. [Differences in growth increments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	Third year growth			
	1973	1974	1975	1976
1973	-			
1974	15.4	-		
1975	0.1	15.3	-	
1976	22.2*	6.8	22.1*	-

Table 18. Comparison of growth rates (G) and mean weight gain (g) for channel catfish for summer (stratified) and winter (destratified) intervals 1973-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 3				
5-23-73	2						
		82.5	1.67	21.0			72.6
8-14-73	2						
		288.0			2.47	169.0	99.1
5-29-74	1 1						
		105.5	2.64	90.2			77.5
9-11-74	6						
		252.0			1.98	240.4	99.3
5-21-75	9 7						
		128.0	-4.00	-103.1			67.7
9-24-75	4						
		236.5			6.03	487.4	99.8
5-19-76	7 5						
		130.0	1.94	70.0			71.9
9-25-76	10						
		231.0			3.13	333.1	97.3
5-14-77	11 6						
		132.0	3.61	180.3			76.6
9-23-77	25						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

Table 19. Mean annual growth increments (mm) (± 95% confidence interval) for white bass in Lake Arbuckle, 1973-76.

Year of growth	Age 1	2	3	4
1973	278.7±14.0 (6)[a]			
1974	265.5± 9.4 (14)	55.2±10.2 (6)		
1975	262.7± 5.9 (15)	51.7± 7.2 (14)	10.7±3.3 (6)	
1976	294.5±30.6 (2)	62.8± 8.5 (15)	17.1±3.3 (14)	9.1±2.8 (6)

[a]Value in ( ) indicates number of fish.

Table 20. Differences in annual growth increments of white bass for first and third years tested for significant difference (0.05 level) by the analysis of variance test, 1973-76. [Differences in growth increments between years are shown; the least significant difference test indicates which differences were significant at the 0.05 level (*).]

Year of growth	First year growth			
	1973	1974	1975	1976
1973	-			
1974	13.2	-		
1975	16.0*	2.8	-	
1976	15.8	29.0*	31.8*	-

Year of growth	Third year growth	
	1975	1976
1975	-	
1976	6.4*	-

stantially greater in the stratified period (Table 21). The loss of weight during the 1976 destratified period could be due to the loss of spawning products just before the sampling period. The best growth rate for the stratified period came in 1976 when AFH was high during the early summer. The next highest growth rate was in 1977 when mixing produced the high average AFH. The lowest growth rate occurred in 1975 when the AFH was also the lowest.

CONCLUSIONS

1. Mechanical mixing of the reservoir in 1977 increased the average amount of available fish habitat (AFH). Using the 2 mg/l DO isopleth as the defining boundary, there was 72.3% AFH in the summer of 1976 when the reservoir was not manipulated and 76.6% AFH in the summer of 1977 when the reservoir was mixed. AFH was greater in early summer of 1976 due to the unusually late date of startification, but was greater in late summer of 1977 due to mixing.

2. The catch of black bullhead per unit of effort (c/f) in gill nets declined from 0.6 in May 1976 to 0.1 in September 1977. During the same period c/f of channel catfish increased from 0.8 to 1.7. It would be highly speculative, however, to attribute such changes in species composition to mechanical mixing without further data.

3. The effect of the mixing device on annual growth can not be determined since mixing took place in 1977 and annual growth for that year was not complete at the time of this study. The annual growth of fish in 1976 was significantly greater than any other year (greater in 12 out of 42 comparisons). This relatively fast growth rate in 1976 could possibly be a case of Lee's phenomenon, in which back-calculated growth for a given year of

Table 21. Comparison of growth rates (G) and mean weight gain (g) for white bass for summer (stratified) and winter (destratified) intervals 1975-77, Lake Arbuckle, Oklahoma.

Median collection date	Sample size*	Growth interval (days)	Stratified period		Destratified period		Available habitat (%)
			$G(10^{-3})$	g	$G(10^{-3})$	g	
			Age group 2				
5-21-75	54						
		128.0	1.22	68.8			67.7
9-24-75	9						
		236.5			0.52	62.0	99.8
5-19-76	41 19						
		130.0	2.76	181.1			71.9
9-25-76	18						
		231.0			-0.83	-104.8	97.3
5-14-77	14 15						
		132.0	2.27	139.6			76.6
9-23-77	10						

*Two sample sizes are given for spring. The first one is for fish of age 4 used to compute overwinter growth during the third year of life.

life (age) is greater during the most recent calendar years due to prior selective mortality of faster-growing fish of older year classes. The fast growth rate could also be due to the large amount of AFH present in the early summer of 1976.

4. Seasonal growth rates were greater during the destratified winter period for gizzard shad and channel catfish but greater during the stratified summer period for white crappie, freshwater drum, and white bass. The bottom-feeding habits of gizzard shad and channel catfish may contribute to better growth during the destratified period when more of the bottom area is available for feeding. White crappie and white bass are pelagic feeders whose growth rate may not be as adversely affected by the loss of bottom habitat.

Of 8 comparisons of growth of fish of the same species and age during the stratified period, growth was greatest 6 times in 1976, once in 1974 and once in 1977. The highest average AFH was available in 1974, during which the second fastest growth rate occurred in 5 of 7 comparisons. The lowest average AFH was available in 1975, during which the slowest growth rate occurred in 4 of 8 comparisons. Growth of fish and AFH appeared to be directly correlated with the exception of 1976. Typically, growth is most rapid in May and June but slows markedly after July (Anderson 1959; Beckman 1943; Sprugel 1954). Consequently, more AFH in early summer would appear to be more beneficial to growth than more AFH in late summer. This situation occurred in 1976 when more AFH was available in early summer than in any other year, and probably also influenced the catch rate, which was substantially higher in the early summer of 1976 than at any other time. The catch rate was probably higher because fish were actively feeding at all depths. The net effect of these circumstances in 1976 was better growth of fishes than in any other year.

5. In summary, stratification appears to have a negative impact on growth of fish by reducing AFH; mechanical mixing increased the amount of AFH in late summer which probably benefitted growth, but the best growth occurred when AFH was expanded in early summer. In order to maximize growth, mixing should begin in early May with the objective of preventing vertical stratification at any time during the summer.

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