VERTICAL DISTRIBUTION OF FISHES, LAKE OF THE ARBUCKLES, OKLAHOMA, IN RELATION TO CONDITIONS OF STRATIFICATION

By

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CONDITIONS OF STRATIFICATION

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CHAPTER I

INTRODUCTION

Although there is conflicting evidence concerning the relationship between standing crop of fishes and unit area of water (Rounsefell 1946 and Carlander 1955), there is little doubt that as total area increases the total standing crop will increase. Since the range in vertical depth distribution of fishes expresses the total volume of water utilized by the fish, the vertical depth distribution of fish is an important variable involved in the total standing crop of fishes.

Deep lakes and reservoirs typically follow an annual cycle of thermal and chemical stratification with stratified conditions occurring during the summer. In the classical case, thermally induced density differences divide stratified lakes into an upper region (epilimnion) which is warm and continuously circulated by the wind, and a lower colder region (hypolimnion) which does not mix with the surface waters (Hutchinson 1957). The two layers are separated by a region (thermocline or metalimnion) characterized by a rapid change in temperature. The degree of enrichment of the waters determines whether the hypolimnion becomes anoxic. In stratified eutrophic lakes, the hypolimnion typically becomes anoxic, or "stagnates", during summer stratification.

The lack of dissolved oxygen (DO) in the hypolimnion reduces available habitat for all aerobic animals (Toetz et al. 1972). Summer stagnation strongly effects the vertical distribution of fishes and may effect their growth and survival. The minimal concentration of DO needed by fish is that required for survival, but much greater concentrations are needed for continued existence for normal activity, growth, reproduction and development (Doudoroff and Shumway 1967). The minimum DO requirements for fish is species specific, dependent upon age, feeding rate and affected by interrelated chemical factors (McKee and Wolf 1963), but there is evidently no percentage of saturation to which the oxygen content may be reduced without causing some adverse effects on growth and the production of fishes (Rohlich 1972:131). Most species of warm-water fishes need at least 1.0 to 3.0 mg/l DO in order to survive (Moore 1942, Moss and Scott 1961, and Mount 1961). A minimum DO concentration of 5 mg/l was given by Doudoroff and Shumway (1967) as a minimum standard for continued existence of varied warm-water fish populations. The Committee on Water Quality Criteria established 4 mg/l as a DO minimum for protecting fish because there is evidence of subacute or chronic damage to several fish below this concentration (Rohlich 1972:132).

Fish tend to avoid low DO concentrations in nature. Dendy (1945) found that fish moved to shallower depths in response to low DO (0.0 to 3.0 mg/l) in the hypolimnion. He postulated that fish would not inhabit oxygen deficient water, but enter the anoxic stratum only temporarily to escape upper warm-water layers. Fast (1968) found that DO depletion in the hypolimnion limited fish to the epilimnion. Mayhew (1963) noted the vertical movements of most species followed closely the location of the thermocline and the depth of DO depletion. He stated that complete stagnation and the resulting depletion of DO within the hypolimnion is undoubtedly the primary factor restricting the vertical movements of fish.

Ziebell (1969) also noted a significant reduction in habitable water in Pena Blanca Lake in Arizona due to development of anoxic conditions during summer stratification. In August, 60% of the bottom area and 46% of the volume of Pena Blanca Lake was essentially denied to fish and their prey due to anoxic conditions. The absence of fish in the anoxic hypolimnion of lakes and reservoirs has been noted by many other investigators (Bardach 1955, Borges 1950, Byrd 1951, Fast 1971, Hile and Juday 1941, Sprugel 1951, Summerfelt and Hover 1968).

Absence of oxygen in the hypolimnion also favors accumulation of reduced compounds which to fish are toxic, repelling or both. Many fish avoid free carbon dioxide levels as low as 1.0 to 6.0 mg/l; above 60 mg/l of free carbon dioxide, many fish have trouble extracting DO from the water (Rohlich 1972:139). Hydrogen sulfide and ammonia are associated with anaerobic conditions which develop during thermal stratification. Ziebell (1969) observed sulfide in excess of 1.0 mg/l, a concentration lethal to fish, in the stratified hypolimnion of an Arizona reservoir (Doudoroff and Katz 1950). Irwin, Symons, and Robeck (1967) concluded that the bottom water of stratified Bullock Pen Lake, Kentucky, contained a concentration of sulfide lethal to fish. They pumped bottom water to a bioassay tank, aerated it sufficiently to increase the DO to about 4 to 5 mg/l and reduce the level of sulfide in the water. In late July, however, fish in the tank were killed after 12 to 96 hours exposure to the aerated bottom water, apparently because the aeration was insufficient to oxidize the accumulated sulfide.

Distribution of fish in a stratified lake may be confined to only a narrow part of the metalimnion when they must avoid both an upper lethal epilimnetic temperature and a lower anoxic hypolimnion. Hile (1936) observed that the cisco (Leucicthyes artedi), a cold-water fish, was limited to a narrow stratum within the thermocline because epilimnetic temperatures were lethal and the hypolimnion was anoxic. Colby and Brooke (1960) reported mortalities for cisco in a southern Michigan lake which could have been anticipated by Hile's observations.

The effects of destratification, either by natural or artificial processes, is to greatly expand the available fish habitat. Mayhew (1963) noted during the fall overturn a rapid expansion of the fish population into regions unoccupied during summer stagnation. Fish in El Capitan Reservoir, California moved to deeper water after destratification with an expression of species specific preferences for different depths (Fast 1968). Leach and Harlin (1970) aerated Lake Roberts, New Mexico in an effort to correct a chronic problem of summer mortality of trout caused by hypolimnetic oxygen depletion and lethal surface temperatures. Artificial destratification, for the explicit purpose of improving fish habitat, has been attempted by Hooper, Ball and Tanner (1953), Johnson (1966), Van Ray (1967), and Fast and St. Amant (1971).

Destratification efforts by Johnson (1966) increased the area of suitable habitat for Coho salmon by 500% and increased smolt survival from 12.9% before destratification to 42.1% during the year of destratification. In this case growth declined, probably due to the tremendous increase in survival and resulting competition for food. Hypolimnetic aeration has improved habitat for salmonids by increasing DO without increasing temperatures to levels lethal to these fish (Hooper, Ball, and Tanner 1952; Fast 1971, 1973).

Although it is evident that some fish can avoid certain stressful physicochemical effects associated with summer stratification by movement to more favorable strata, it is also known that these abiotic conditions have a significant impact on the productivity of a total ecosystem (Toetz, Summerfelt and Wilhm 1972). It has been postulated that destratification would benefit fish populations by increasing available habitat for both fish and their prey organisms, resulting in increased fish growth and survival. Mayhew (1963) indicated that fish growth is retarded by stratification. Stewart, Shumway and Doudoroff (1967) and Andrews, Murai and Gibbons (1973) found that food consumption, growth, and food conversion efficiency of fish were significantly reduced at DO levels adequate for survival, but below air saturation. This would indicate that the threshold level for an adverse effect on growth is any reduction of DO below air saturation levels. Additional studies are needed on the relationship between short-term growth rates, fish depth distribution and physicochemical changes associated with stratification.

In the present study fish were captured with vertically stratified horizontally set variable mesh gill nets. These data were used to (i) relate the vertical depth distributions of five selected species to conditions of stratification present in the lake, and (ii) to determine whether mechanical mixing could alter the DO profile, at least locally, such as to extend the vertical depth distribution of fish.

CHAPTER II

PROCEDURES

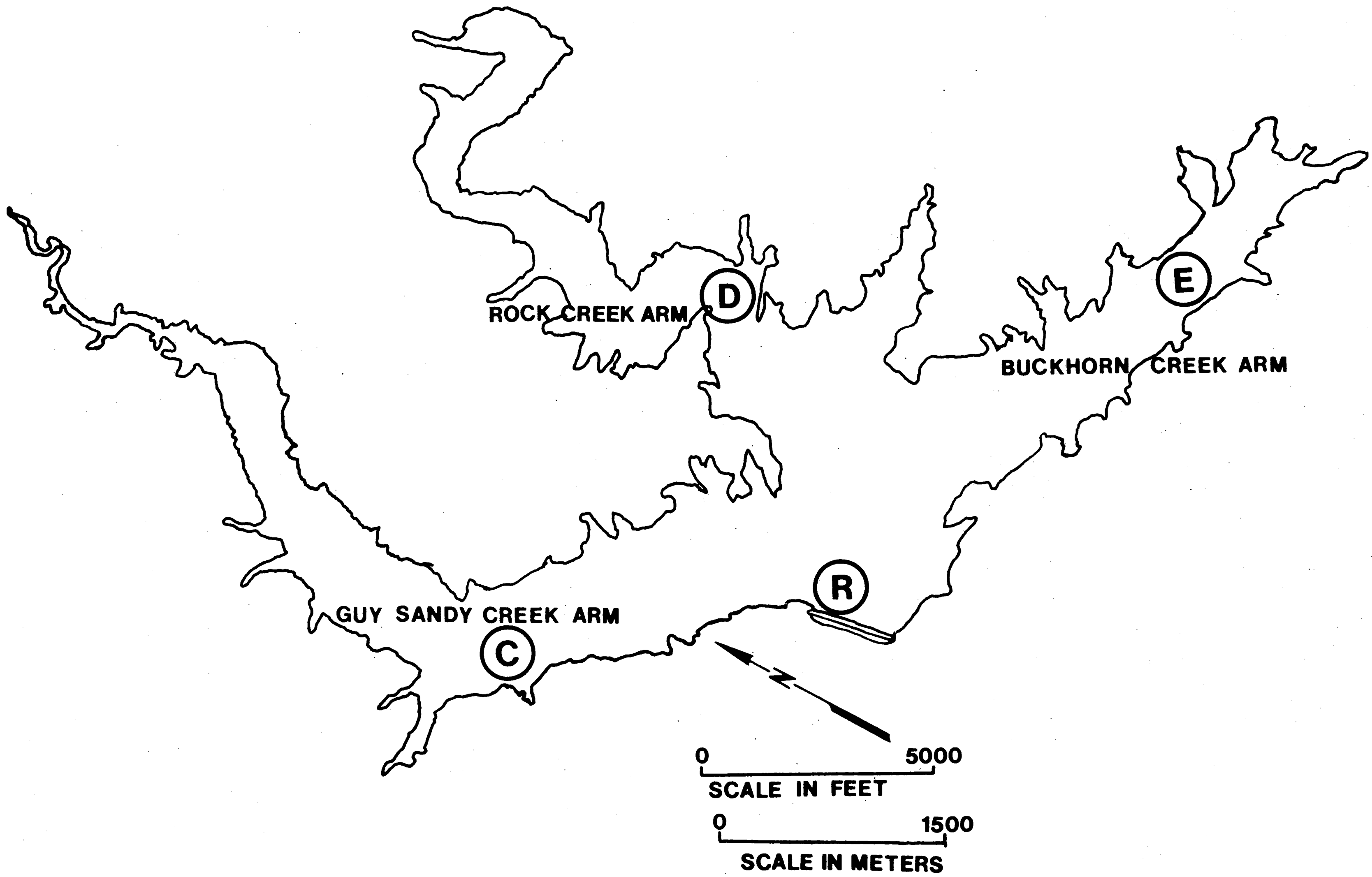
Description of Study Area

Lake of the Arbuckles (hereinafter, Arbuckle Lake) 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 Arbuckle Lake in 1968.

Collection Methods

Fish were collected with experimental gill nets, each net was 3.05 m deep by 45.73 m long consisting of six 7.12 m panels. Individ-

Figure 1. Lake of the Arbuckles showing four fish collection sites.


ROCK CREEK ARM
D
BUCKHORN CREEK ARM
E
GUY SANDY CREEK ARM
C
R
0
5000
SCALE IN FEET
0
1500
SCALE IN METERS

ual panel square mesh sizes were 1.27 cm, 2.54 cm, 3.81 cm, 5.08 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 ecosounder.

Horizontal gill nets were used rather than vertical gill nets because: (1) they are easier to maintain and use than the vertical gill nets; (2) the catch per unit effort is greater in the horizontal gill nets than in the vertical gill nets; (3) the vertical gill nets are potentially dangerous surface obstructions--the National Park Service, which has jurisdiction over Arbuckle Lake, probably would have prohibited use of the vertical nets.

Temperature and DO measurements were taken weekly at 1 m intervals at all sites using three types of commercial DO probe and meter assemblies, each having a thermistor attached for manual or automatic temperature compensation. The thermistor was standardized weekly with the internal adjustment mechanism. The DO probe was standardized weekly with a modified winkler titration method as described in Standard Methods for the Examination of Water and Wastewater (1965). Standardized titration reagents were kept refrigerated and replaced every two months. Temperature and DO measurements were not taken from 18 May to 20 June 1973 due to a malfunctioning DO probe.

Pump Operation

During the summer of 1973, the Bureau of Reclamation attempted destratification by using a compressed air gun similar to that described by Bryan (1965). The device had a pumping capacity of 42-50.4 m^3/min. The pump was started 10 July 1973 and operated continuously, except for a few minor shutdowns, until 11 October 1973. During the summer of 1974 and 1975, J. E. Garton attempted to destratify the reservoir using an axial flow pump, larger than, but similar to a pump described by Quintero and Garton (1973). The pump was operated at 5 RPM from 17 July to 24 July 1974, 9 RPM from 24 July to 2 August 1974 and 12 RPM from 2 August thru 31 August 1974, giving a pumping capacity of 196.0 to 832.7 m^3/minute. The pump was modified in 1975 and operated at 18 RPM from 2 June to 2 July and 20 RPM from 2 July thru 12 September 1975, giving a pumping capacity of 704.0 to 783.5 m^3/minute.

Experimental Design

Four sites were used to make the fish collections: (1) site R was located at the dam within 200 m of the mixing device; (2) site C was located in Guy Sandy Creek arm, 2,067 m from the mixing device; (3) site D was located in Rock Creek arm, 2,250 m from the mixing device; and (4) site E was located in Buckhorn Creek arm, 3,033 m from the mixing site (Figure 1). Site R was located near the mixing device to measure any local effects of the mixing device on the fish population. Sites C, D and E were located as far up the respective major arms of the lake as possible where the lake was still of sufficient depth to allow for fishing nets at all depth intervals. Sites C, D and E would represent a control area, least likely to be affected by the pump as compared with site R.

The four depth intervals chosen were selected to sample the epilimnion, metalimnion and hypolimnion. One series of nets (one 0-5 m, one 5-10 m, one 10-15 m and one 15-20 m) was set at each of sites C, D and E each week. Three series of nets were set at site R each week.

Therefore, half the sampling took place at the experimental mixing site (R) and the other half at sites C, D and E which represent random samples from the control area of the lake. Nets were fished for approximately 24-hour periods, but the catch was adjusted to express number of fish per 24 hours. A mean depth of capture was calculated for each major species, at each week for each site and for all sites combined. This calculation was basically a weighted mean in which it was assumed that the average point of capture was at the mid-point of each depth interval. Throughout this study the depth of capture will be utilized to define the depth distribution of fish, consequently the two terms will be used interchangeably.

In 1973, fish collections were made for 15 continuous weeks from 14 May to 24 August and an additional collection was obtained 18-21 October 1973. In 1974, collections commenced 10-14 March 1974 with the weekly collection schedule beginning 20 May and continuing through 23 August 1974. A final 1974 collection was made 9-13 September to monitor growth and distribution after the lake had destratified. In 1975, weekly collections commenced 12 May and continued through 22 August; a collection was obtained 22-26 September after the lake had destratified.

Statistical Design

Each year, the mean depth of capture data for each species was subjected to a two-way analysis of variance (AOV) test (Sokal and Rohlf 1969:320-328) to determine the significance of observed differences between sites and weeks. The mean depth of capture of fish at site R (mixed site) was tested against sites C, D and E combined (unmixed sites) using a paired t-test. In no instance was this test significant when the AOV test indicated a lack of significance between sites; therefore, the significant f for the AOV test of the difference between the sites largely reflected differences among sites rather than between the experimental and control areas. The combined mean depth of capture for each year of a species was compared to both other years using a weekly paired t-test.

The weekly depths of the 2 and 6 mg/l DO isopleths were subjected to a two-way AOV test to: (1) test for no difference between areas (mixed versus unmixed) averaged over sites and weeks, (2) test for no difference among weeks averaged over sites and areas, (3) test for no interaction of areas and weeks.

Correlation coefficients were calculated to determine the relationship between mean depth of capture of each of the five species of fishes to DO and water temperature. Using temperature as the independent variable, mean depth of capture was related to the depth of three temperature contours, the 23, 25 and 27^{o}C isotherms. Using DO as the independent variable, mean depth of capture was related to the depth of four DO isopleths, the 2, 4, 6 and 8 mg/l DO contours. The mean depth of capture was a weighted average for all sites combined and the DO and temperature values were also averages for all sites combined.

CHAPTER III

RESULTS

Seasonal Profiles of Temperature and DO

Arbuckle Lake was thermally stratified by mid-May in each of the three years of study, however, at this time a DO deficiency was present only in the bottom 1-5 m of the hypolimnion (Figure 2). Between early May and early July, density differences increased and natural circulation from the epilimnion to the hypolimnion was eliminated. By early June, water below about 12 m contained less than 2 mg/l DO and by early July all lake water below 12 m was generally anoxic.

In 1973, the lake remained stratified through August, no samples were obtained in September, but the lake was thermally uniform down to 22 m by 20 October (Figure 2). The thermal profiles were fairly constant at similar depths over all four sites on 1 August 1973 (Table 1). The DO profiles were also similar among sites during the same time period (Table 2) but DO concentration was slightly higher in the hypolimnion at site R (mixing site) than at the three control sites. The air gun was operating at this time and appears to have had little or no effect upon the temperature and DO profiles.

In 1974 the lake again stratified by mid-May and the hypolimnion became anoxic through June and July (Figure 2). Garton's pump commenced operation at 5 RPM on 17 July; on 24 July the speed was

Figure 2. Temperature and DO profiles for 1973-75.

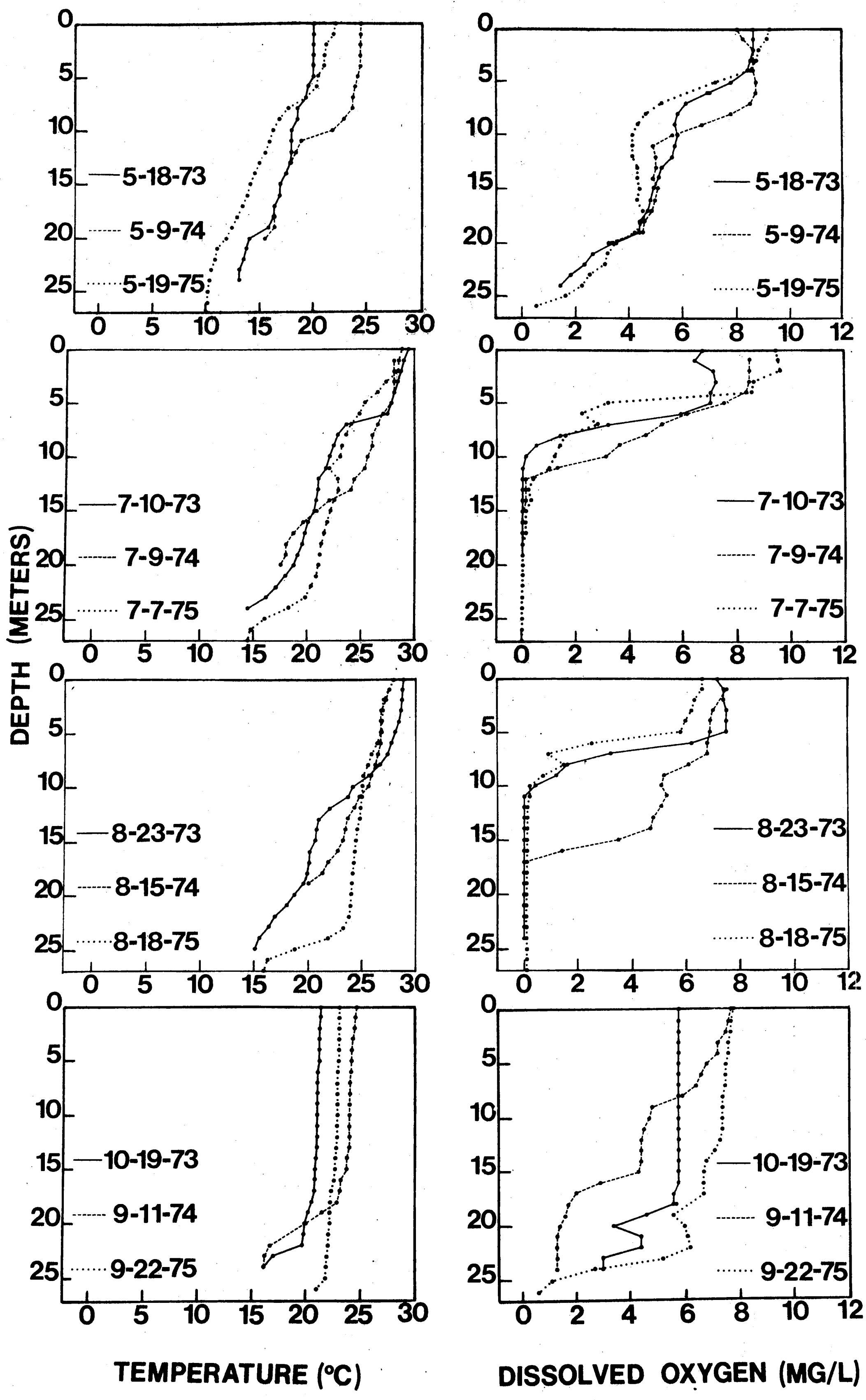

DEPTH (METERS)
5-18-73
5-9-74
5-19-75
7-10-73
7-9-74
7-7-75
8-23-73
8-15-74
8-18-75
10-19-73
9-11-74
9-22-75
TEMPERATURE (°C)
DISSOLVED OXYGEN (MG/L)

Table 1. Selected temperature (^{o}C) profiles at sites C, D, E (control sites) and R (mixing site) during 1973 thru 1975.

Depth (m)	1 August 1973				5 August 1974				4 August 1975			
	C	D	E	R	C	D	E	R	C	D	E	R
Surface	28.0	28.0	28.0	28.0	27.8	28.0	28.0	27.5	28.6	28.2	29.1	29.5
1	28.0	28.0	28.0	28.0	27.8	28.0	28.0	27.5	28.6	28.1	29.0	29.2
2	28.0	28.0	28.0	27.9	27.8	28.0	28.0	27.5	28.2	28.0	29.0	29.1
3	27.9	28.0	28.0	27.8	27.8	28.0	28.0	27.5	28.2	28.0	28.9	29.1
4	27.9	27.9	27.9	27.6	27.5	28.0	27.8	27.5	28.1	28.0	28.2	27.9
5	27.9	27.6	27.9	27.3	27.5	27.8	27.5	27.4	26.2	27.0	26.2	26.9
6	27.9	27.1	27.9	27.1	27.5	27.8	27.5	27.2	26.2	26.6	25.8	26.2
7	25.9	27.0	27.7	27.0	27.4	27.5	27.5	27.1	25.8	25.4	25.2	25.8
8	25.0	26.0	27.0	26.1	27.2	27.5	26.8	27.1	25.0	25.0	25.1	25.2
9	24.1	22.9	24.7	23.1	26.8	26.2	26.5	26.9	24.8	24.9	25.0	25.1
10	22.9	22.5	23.2	22.1	25.8	26.0	26.2	25.2	24.5	24.8	24.9	25.0
11	21.7	21.8	21.8	21.0	25.2	25.5	25.8	25.1	24.2	24.5	24.8	24.9
12	21.0	21.3	21.2	20.5	24.5	25.0	25.2	24.5	24.2	24.2	24.5	24.5
13	-	21.0	21.1	20.3	-	24.5	24.2	24.5	24.1	24.2	24.2	24.2
14	-	20.6	20.8	20.0	-	23.9	23.9	24.0	24.0	24.1	24.2	24.2
15	-	20.1	20.5	19.9	-	-	22.2	22.0	23.9	24.0	-	24.2
16	-	20.0	-	19.8	-	-	-	20.5	-	23.8	-	24.0
17	-	20.0	-	19.5	-	-	-	19.8	-	-	-	23.9

Table 2. Selected DO (mg/1) profiles at sites C, D, E (control sites) and R (mixing site) during 1973 thru 1975.

Depth (m)	1 August 1973				5 August 1974				4 August 1975			
	C	D	E	R	C	D	E	R	C	D	E	R
Surface	7.6	7.3	7.9	7.7	8.1	8.5	8.4	8.0	7.9	7.8	8.3	8.2
1	7.6	7.3	7.9	7.7	8.1	8.5	8.4	8.0	7.9	7.8	8.3	8.3
2	7.6	7.2	7.8	7.7	8.0	8.4	8.3	7.8	7.7	7.6	8.1	8.3
3	7.6	7.1	7.7	7.7	7.8	8.2	8.1	7.5	7.2	7.3	7.9	8.3
4	7.5	6.5	7.6	7.6	7.6	7.9	8.0	7.2	6.7	6.8	6.2	4.2
5	7.2	5.6	7.4	7.6	7.4	7.6	7.8	7.0	1.9	1.7	0.4	1.4
6	7.0	4.9	7.1	7.6	7.2	7.3	7.6	6.8	0.6	0.4	0.2	0.3
7	3.2	2.1	6.2	7.3	7.1	7.2	3.8	6.8	0.2	0.2	0.1	0.2
8	0.4	0.2	4.1	5.2	6.8	6.2	1.9	6.6	0.0	0.1	0.1	0.1
9	0.2	0.1	0.2	0.4	0.0	0.0	0.1	6.5	0.0	0.1	0.1	0.1
10	0.2	0.1	0.2	0.5	0.0	0.0	0.1	6.1	0.0	0.1	0.1	0.1
11	0.2	0.1	0.2	0.5	0.0	0.0	0.1	6.2	0.0	0.1	0.0	0.1
12	0.2	0.1	0.2	0.5	0.0	0.0	0.1	6.4	0.0	0.1	0.0	0.0
13	–	0.1	0.2	0.5	–	0.0	0.1	6.4	0.0	0.1	0.0	0.0
14	–	0.1	0.2	0.5	–	0.0	0.0	3.8	0.0	0.1	0.0	0.0
15	–	0.1	0.2	0.5	–	–	0.0	3.4	0.0	0.1	–	0.0
16	–	0.1	–	0.5	–	–	–	0.0	–	0.1	–	0.0
17	–	0.2	–	0.5	–	–	–	0.0	–	–	–	0.0

increased to 9 RPM. Operation of the pump between 17 July thru 1 August appeared to have no effect on the temperature or DO profiles (Summerfelt and Gebhart 1976). On 2 August, the pumping rate was increased to 12 RPM which was followed by a pronounced change in the DO profile on the third day at site R located approximately 40 m from the pump (Table 2). A DO concentration of 3.4 mg/l was found at 15 m at site R on 5 August, approximately 7 m deeper than occurred before the increased pumping. DO concentrations at the control sites on 5 August were 0.0 to 0.1 mg/l below 8 m (Table 2). The effect of the pump was apparently quite localized as Toetz (1976) did not find substantial increases in DO at a site approximately 200 m from the pumping device. On 5 August the temperature profiles at site R were not substantially different from the control sites (C, D and E) (Table 1).

The differences in weekly depths of the 2 and 6 mg/l DO isopleths between the mixed and unmixed areas were subjected to a two-way AOV test. For the entire summer of 1974, there was not a significant difference in the 6 mg/l DO isopleth between the mixed versus the unmixed area (Table 3). There was a significant difference ($P<.05$) between weeks, indicating a changing DO profile over the summer. There was not a significant interaction between areas and weeks implying a lack of any specific weekly changes at an area.

The difference between the average depth of the 2 mg/l DO isopleth at the control areas (9.3 m) versus the mixing area (10.4 m) was significant ($P<.05$) (Table 3). There was also a highly significant difference ($P<.01$) between weeks and for the area by weeks interaction which implies that the pump had a specific effect in increasing DO at site R, however, the effect was apparently very localized.

Table 3. Summary of two-way analysis of variance comparison of depth of 2 and 6 mg/l DO isopleths in 1974.

Source of variation	df	SS	MS	F
		2 mg/l		
Area	1	8.1	8.1	20.2*
Weeks	9	86.0	9.6	13.7**
A x W	9	32.3	3.6	5.1**
Sites/A	2	0.7	0.4	
Sites x W/A	18	12.4	0.7	
		6 mg/l		
Area	1	9.3	9.3	2.3
Week	13	110.2	8.5	2.6*
A x W	13	69.1	5.3	1.6
Sites/A	2	8.2	4.1	
Sites x W/A	26	86.8	3.3	

*$F_{.05}[1, 2] = 18.5$; $[13, 26] = 2.1$

**$F_{.01}[9, 18] = 2.5$

By 11 September 1974, the lake was nearly isothermal to 18 m, 2 mg/l DO was present to 17 m, and 1.5 mg/l DO was present at all depths (Figure 2). Duffer and Harlin (1971) found similar conditions occurring in Arbuckle Lake over a month later in 1968-69, indicating that DO was available at deeper levels earlier in 1974 than in past years. Although this difference could be an annual variation, in relation to annual variations in climatic conditions, the changes in 1974 were substantially different than in 1968, 1969, or 1973.

In 1975, the lake was thermally stratified by mid-May and already exhibiting DO depletion in the hypolimnion (Figure 2). The pump began operation on 2 June at 18 RPM and on 2 July was increased to 20 RPM. Thermal differences between the top and bottom were much less than would have been likely without pumping. However, the pumping did not create isothermal conditions (Figure 2). Consequently, the lake did not destratify. The temperature profiles were nearly uniform at all four sites on 4 August when the pump was operating at 20 RPM, with the bottom 8 m substantially warmer than past years (Table 1).

DO profiles were nearly uniform over all four sites on 4 August with the pump operating at 20 RPM (Table 2). The AOV test indicated no significant difference ($P<.05$) in the 6 mg/l DO isopleth between the mixed and unmixed areas (Table 4). There was a highly significant difference ($P<.01$) between weeks and no significant interaction between areas and weeks. These statistical tests indicate a uniform change in the depth of the 6 mg/l DO isopleth occurring in both areas over the summer interval.

There was a highly significant difference ($P<.01$) between areas, weeks, and for the area by week interaction for the 2 mg/l DO isopleth

Table 4. Summary of two-way analysis of variance comparison of depth of 2 and 6 mg/l DO isopleths in 1975.

Source of variation	df	SS	MS	F
		2 mg/l		
Area	1	33.7	33.7	168.5**
Week	12	288.5	24.0	26.7**
A x W	12	94.9	7.9	8.8**
Sites/A	2	0.3	0.2	
Sites x W/A	24	22.3	0.9	
		6 mg/l		
Area	1	0.0	0.0	0.0
Week	14	132.5	9.5	3.6**
A x W	14	5.5	0.4	0.1
Sites/A	2	15.5	7.8	
Sites x W/A	28	72.3	2.6	

**$F_{.01}$[1, 2] = 98.5; [12, 24] = 3.0; [14, 18] = 2.8

(Table 4). The isopleth at site R was significantly deeper than at sites C, D and E. Differences between areas in this case is not due to mixing, but to the different lake depths at the two areas. In the early summer when the lake thermally stratifies, hypolimnetic oxygen depletion begins near the bottom where BOD is the greatest. The depths of DO isopleths will vary between sites during this hypolimnetic DO depletion phase. This same phenomenon can explain the highly significant area by week interaction while the highly significant variation among weeks is attributable to the effect of stratification on the DO profile.

The depths of the DO isopleths were less in 1975 than in 1973 or 1974 possibly due to increased bacterial action resulting from the increased temperature of the hypolimnion. The lake appeared to mix earlier in 1975 (Figure 2) than in 1968-69 (Duffer and Harlin 1971). On 22 September 1975 there was 6 mg/l DO available at 23 m which is a higher concentration at a substantially deeper depth than was available in mid-October 1968-69.

The reduction of available fish habitat is quite substantial in Arbuckle Lake during summer stratification. Using the 2 mg/l DO isopleth as the limiting concentration for suitable fish habitat, Summerfelt and Gebhart (1976) calculated the amount of available fish habitat for 1973-75. In 1973, they found the area of available habitat was reduced to a low of 38% of the total area and 52% of the total volume. In 1974 the available area and volume was reduced as much as 46% and 61% respectively of the total on 22 July. On 11 August 1975, stratification reduced available habitat to only 29% of the area of the lake basin and 41% of the lake's volume. They attributed the increase in available habitat in 1974 to the operation of the Garton axial flow pump. In 1975 the pump lowered the temperature differential between the top and bottom, but not enough to eliminate the thermal density differences and destratify the lake. This increased the temperature of the bottom water (Figure 2) which reduced its oxygen carrying capacity and possibly increased the biochemical processes which consume oxygen. The net result was less DO and available habitat in the lake during the summer of 1975 than in the two previous years.

High surface water temperatures also decreased habitable water concurrent with the progressive expansion in the volume of the anoxic hypolimnion. Between 13 June and 11 August 1975, epilimnetic water temperatures increased from 22.0 to 29.8^{o}C, respectively. Because 29.8^{o}C exceeds the preferred temperature of most species of fish (Ferguson 1958), fish in Arbuckle Lake should have shown avoidance of the warm surface layers and sought out a water layer close to the thermocline. High surface temperature would have the effect of sandwiching the fish in a narrow layer of water between the anoxic hypolimnion and the thermally oppressive upper epilimnion. The depth arrangement of the nets did not allow the discrimination of differences in mean depth from less than 5 m.

Relation Between Depth of Capture and Temperature and DO

Correlation coefficients were calculated to determine the relationship between mean depth of each of five species of fishes (gizzard shad, white crappie, freshwater drum, black bullhead and channel catfish) to DO and water temperature. Using temperature as the independent variable, mean depth distribution of each of five species was related to the depth of three temperature contours: the 23, 25 and 27°C isotherms. None of the 15 correlation coefficients were significant at $P<.05$. Prior to and after stratification when the lake was homothermal and mixing fish were unable to select a thermal preference. Alternatively, when the lake was stratified fish had to avoid the cooler but anoxic strata even though these strata were closer to their preferred temperature.

The correlation between mean depth of capture and depth of the 2, 4, 6 and 8 mg/l DO isopleths were examined for 1974 and 1975 for intervals when there was a vertical gradient in DO. At this time, temperatures were never above a lethal limit so fish were not limited in selection by a lethal factor as was the case for the temperature gradient. Correlation coefficients between DO and fish depth distribution were not calculated for the 1973 data due to inadequate DO measurements. Three of the twenty correlation coefficients between DO and depth of capture were significant in 1974 (Table 5). Eleven of the twenty correlation coefficients were significant in 1975. These relationships will be discussed by species.

The depth distribution of each species of fish is illustrated with polygons drawn to approximate the percentage of fish captured at each depth interval. The numbers at the sides of the polygons represent the percentage of the total number of that particular species captured at that depth in each interval. The number in parenthesis at the top of the polygon represents the total number of the species caught in that time interval. The mean depth distribution of fish for each time interval is represented in the figures by $\bar{X}$. The horizontal line traversing

Table 5. Correlation coefficients (r) between weekly depth distribution of five species of fish and selected DO isopleths, Arbuckle Lake, 1974-75.

Species	Oxygen concentration (mg/l) 2	4	6	8
		1974		
Gizzard shad	0.441	0.267	0.218	0.440
White crappie	0.600	0.667*	0.639*	0.603
Freshwater drum	0.223	0.493	0.629*	0.670
Black bullhead	0.336	0.518	0.451	-0.018
Channel catfish	-0.381	-0.311	-0.392	0.401
df	8	10	13	6
		1975		
Gizzard shad	0.492	0.622*	0.439	0.293
White crappie	0.845**	0.871**	0.866**	0.558
Freshwater drum	0.870**	0.897**	0.852**	0.591
Black bullhead	0.648**	0.696**	0.777**	0.546
Channel catfish	0.559*	0.497	0.416	0.225
df	13	13	13	8

*Significant at P = .05

**Significant at P = .01

the polygons represents the depth down to which at least 2 mg/1 DO was present.

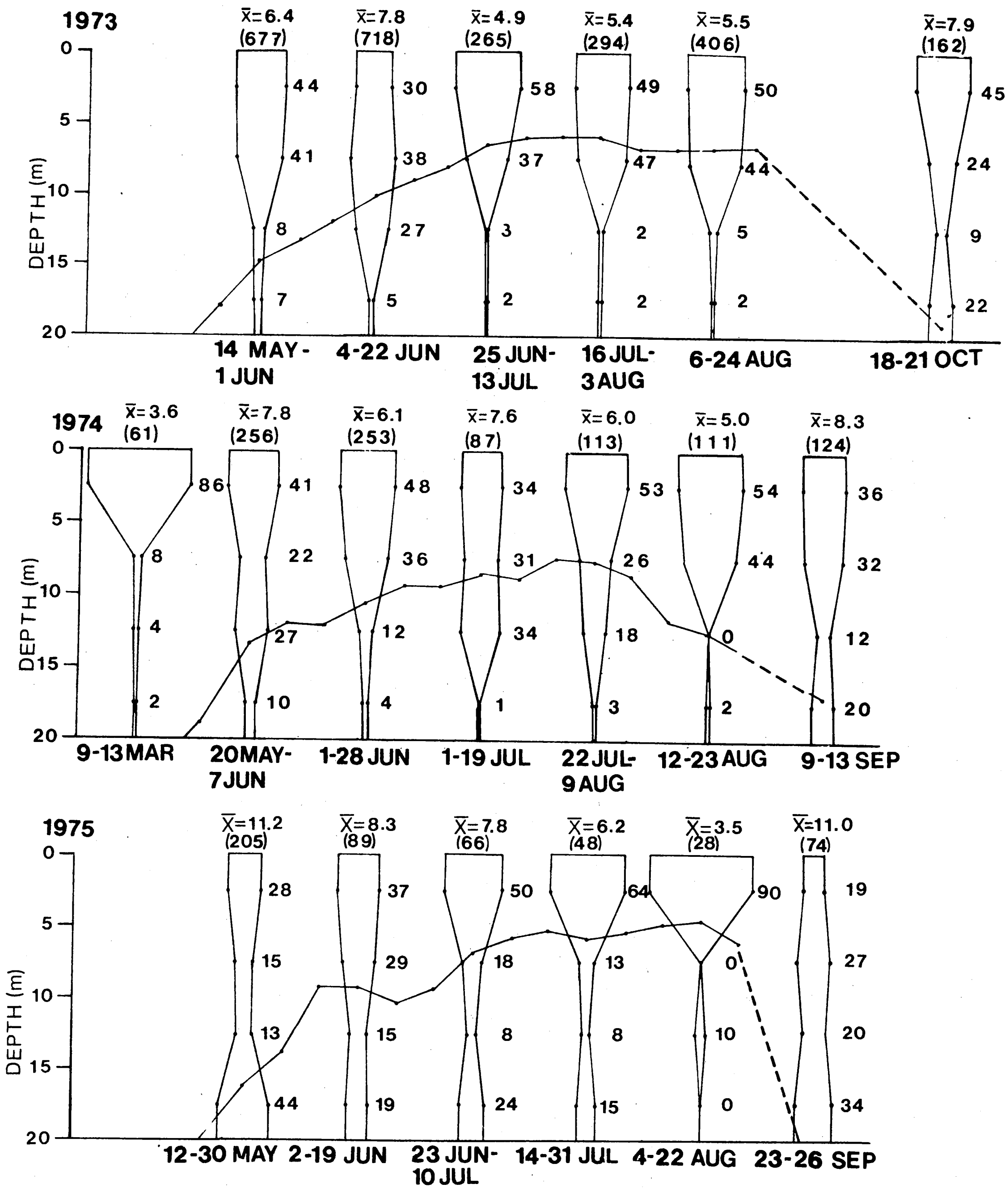
The species composition of the gill net catch dictated which species would be selected for study. The five most numerous species in 1973, gizzard shad, white crappie, black bullhead, freshwater drum, and channel catfish, were selected for detailed analysis. These five species made up 92.23% of the total catch in 1973, 88.42% in 1974 and 80.89% in 1975 (Summerfelt and Gebhart 1976). These five species remained the most numerous in the catch in 1974 and 1975 with the exception that white bass replaced channel catfish as the fifth most abundant species in both years. For the sake of continuity, the same five species of fish were studied in 1974 and 1975 as originally in 1973.

Because preferences and tolerances to temperature, DO, light and other environmental factors, which dictates respective depth distributions, were expected to vary by species, the results are presented for each species separately.

Gizzard shad (Dorosoma cepedianum)

Gizzard shad were found principally in the upper 5 meter interval (86%) during the early March sample in 1974 (Figure 3). They were distributed throughout the water column in the early summer (12 May-7 June) during all three years of the study, but by mid-summer (14 July-9 August) of each year, the percentage distribution of the catch was substantially greater in the 0-5 m and 5-10 m nets than in the deeper nets. By late-summer (4-24 August) they had almost completely deserted the region below 10 m as indicated by the low percentage of the catch in

Figure 3. Depth distribution of gizzard shad represented by polygons that approximate the percentage (shown alongside the polygon) of fish captured at each depth interval, in relation to the 2 mg/l DO isopleth (curve); the $\bar{X}$ represents the mean depth (m), and the value in ( ) the total adjusted number caught in that interval.


1973
X̄=6.4 (677)
X̄=7.8 (718)
X̄=4.9 (265)
X̄=5.4 (294)
X̄=5.5 (406)
X̄=7.9 (162)
DEPTH (m)
14 MAY-1 JUN
4-22 JUN
25 JUN-13 JUL
16 JUL-3 AUG
6-24 AUG
18-21 OCT
1974
X̄=3.6 (61)
X̄=7.8 (256)
X̄=6.1 (253)
X̄=7.6 (87)
X̄=6.0 (113)
X̄=5.0 (111)
X̄=8.3 (124)
9-13 MAR
20 MAY-7 JUN
1-28 JUN
1-19 JUL
22 JUL-9 AUG
12-23 AUG
9-13 SEP
1975
X̄=11.2 (205)
X̄=8.3 (89)
X̄=7.8 (66)
X̄=6.2 (48)
X̄=3.5 (28)
X̄=11.0 (74)
12-30 MAY
2-19 JUN
23 JUN-10 JUL
14-31 JUL
4-22 AUG
23-26 SEP

those depth intervals. After the fall overturn in October, 1973, gizzard shad distributed down to deeper depths. An earlier autumnal partial circulation was observed in 1974 and 1975 which was attributed to the operation of the axial flow pump. The depth distribution of gizzard shad shows the fish used the entire water column and distributed significantly deeper after the autumnal partial circulation (Figure 3). Thus the pumping shortened the period of summer stagnation and effectively increased fish habitat.

A weighted mean depth of capture was calculated for each site and for all sites combined for each week; the date given in the table is the approximate midpoint of each week (Table 6). There were 11 weeks of sampling when gizzard shad were not captured at a site, consequently, a mean depth distribution could not be calculated for that site. This occurred during late July and August in all cases and site E was the location of the missing data point in 8 of the 11 cases.

Differences in mean depth of capture among sites and weeks was examined by a two-way AOV test to test the hypothesis that the observed differences were within the expected range due to sampling error. There was not a significant difference among weeks in 1973 or 1974, but there was a highly significant difference among weeks in 1975 (Table 7). This indicates a fairly uniform depth distribution over the summer period in 1973 and 1974, but a changing distribution among weeks in 1975, probably due to the expanded anoxic hypolimnion which occurred in 1975.

A weekly paired t-test was also calculated between years using the combined sites mean depth distribution and comparing only the matching calendar weeks (Table 8). There was not a significant difference in depth distribution among any of the combinations of years indicating a

Table 6. Weekly mean depth of capture (m) of gizzard shad, 1973 thru 1975; sites C, D and E were from the control area, site R was close to the mixing device.

	March	May			June				July					August			Sept.		Oct.	Total
	12	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	11	24	19	mean
1973																				
Site C	-	4.4	6.6	7.7	9.8	5.6	7.1	3.9	3.3	8.6	5.8	4.2	8.8	7.9	5.0	7.9	-	-	7.9	6.5
Site D	-	8.2	6.9	7.3	8.9	8.6	7.2	5.2	6.9	5.9	4.8	6.4	5.7	5.2	4.1	7.5	-	-	7.1	6.6
Site E	-	5.7	6.2	3.8	8.7	6.2	4.8	2.9	2.5	7.5	8.1	12.5	3.9	3.7	7.1	8.9	-	-	5.6	6.1
Site R	-	4.1	6.2	9.6	10.1	8.6	8.9	4.9	2.7	3.6	5.0	5.6	8.6	7.8	6.1	3.9	-	-	11.6	6.7
Combined	-	5.1	6.3	7.5	9.4	7.5	7.5	4.2	4.8	5.9	5.4	5.4	6.6	5.8	5.2	7.2	-	-	8.0	6.4
1974																				
Site C	3.0	-	8.6	5.0	4.2	6.7	5.4	9.4	7.0	2.5	2.5	6.7	2.5	2.5	2.5	3.7	11.1	-	-	5.2
Site D	7.3	-	5.5	6.6	5.7	7.5	5.6	10.9	7.5	7.5	9.9	12.0	12.5	7.5	9.9	7.5	7.3	-	-	8.2
Site E	7.5	-	6.4	3.3	4.5	4.4	3.3	3.9	9.5	2.5	2.5	--	2.5	--	--	--	10.8	-	-	5.3
Site R	3.2	-	12.5	10.2	11.0	8.9	6.4	8.7	5.5	7.5	5.0	2.5	4.8	3.5	5.0	6.2	7.0	-	-	6.7
Combined	3.7	-	9.0	6.5	5.9	7.3	5.4	8.5	6.3	6.6	4.9	9.0	4.7	3.6	5.4	6.0	8.3	-	-	6.3
1975																				
Site C	-	13.4	11.4	12.5	10.0	13.4	7.8	4.8	9.2	12.5	10.1	7.4	3.8	4.4	--	5.8	-	7.9	-	8.6
Site D	-	5.0	12.5	10.6	6.2	5.0	10.7	5.4	8.4	7.0	--	12.5	2.5	2.5	2.5	--	-	3.5	-	6.6
Site E	-	12.4	11.3	7.0	17.5	2.5	4.1	5.8	2.5	2.5	2.5	2.5	--	--	--	--	-	9.5	-	5.9
Site R	-	9.2	10.9	13.0	8.4	7.3	8.2	4.4	13.6	13.9	6.1	7.1	10.7	2.5	2.5	3.6	-	13.6	-	8.4
Combined	-	10.7	11.2	11.8	9.1	7.5	8.2	4.9	10.9	11.2	6.4	7.4	4.2	3.5	2.5	4.1	-	11.0	-	7.8

- Indicates no sampling for that date

-- Indicates that sampling was conducted but gizzard shad were not captured

Table 7. Summary of two-way analysis of variance comparison of average depth of capture of gizzard shad (df = degrees of freedom, SS = sum of squares, MS = mean square).

Source of variation	df	SS	MS	F
		1973		
Weeks	15	107.85	7.19	1.72
Sites	3	3.09	1.03	0.25
Error	45	188.10	4.18	
		1974		
Weeks	15	108.75	7.25	1.09
Sites	3	95.31	31.77	4.78**
Error	45	298.80	6.64	
		1975		
Weeks	15	446.25	29.75	2.89**
Sites	3	86.10	28.70	2.78
Error	45	463.50	10.30	

**$F_{.01}[3, 45] = 4.27$; $[15, 45] = 2.48$

Table 8. Summary of t-test comparisons between average depth of capture of gizzard shad at sites C, D, and E combined versus site R and between years using the combined sites depth distributions.

Site	Average mean depth	Standard deviation	df	t-value
		1973		
C,D,E	6.47	1.28	15	-0.40
R	6.70	2.65		
		1974		
C,D,E	6.28	1.68	15	-0.52
R	6.74	2.88		
		1975		
C,D,E	7.04	2.74	15	-1.58
R	8.43	3.95		
		1973 vs. 1974		
1973 combined	6.33	1.37	13	-0.04
1974 combined	6.36	1.62		
		1973 vs. 1975		
1973 combined	6.25	1.36	14	-1.57
1975 combined	7.57	3.18		
		1974 vs. 1975		
1974 combined	6.23	1.17	13	-1.26
1975 combined	7.35	3.18		

constant annual trend of gizzard shad depth distribution over the comparable summer period (May thru August) that was uninterrupted by the mixing device.

Correlation coefficients were calculated for weekly mean fish depth and the depth of selected DO contours in 1974 and 1975 (Table 5). Only one of the eight correlations was significant. There was a significant correlation between gizzard shad depth distribution and the 4 mg/l DO isopleth in 1975. Dissolved oxygen was not an important controlling factor in the early summer when DO levels are fairly high throughout the water column. Few gizzard shad were found near the bottom when that stratum was anoxic in mid-summer. Nearly all gizzard shad captured in the anoxic strata were dead, indicating that they died in the nets from suffocation.

They were probably in search of food in the anoxic waters since a predominant part of the food of gizzard shad is bottom detritus (Baker and Schmitz 1971). The percentage of gizzard shad captured in the 15-20 interval was significantly larger in 1975 than in both 1973 and 1974. The axial flow pump was in operation during most of this time and did lower the temperature differential from top to bottom. It has been postulated that the mixing may have reduced some of the inhibiting toxic compounds such as ammonia or hydrogen sulfide which build up at the bottom of the anoxic hypolimnion, thus allowing gizzard shad to at least make feeding forays into the oxygen deficient waters. The average mean depth distribution of gizzard shad was deeper at the mixing site than the unmixed sites, although the difference was not significant. By late summer (August) few shad were captured below 10 m. It appears obvious that DO is controlling their depth distribution at this time since they are found in deeper water after it is reareated following autumnal partial circulation.

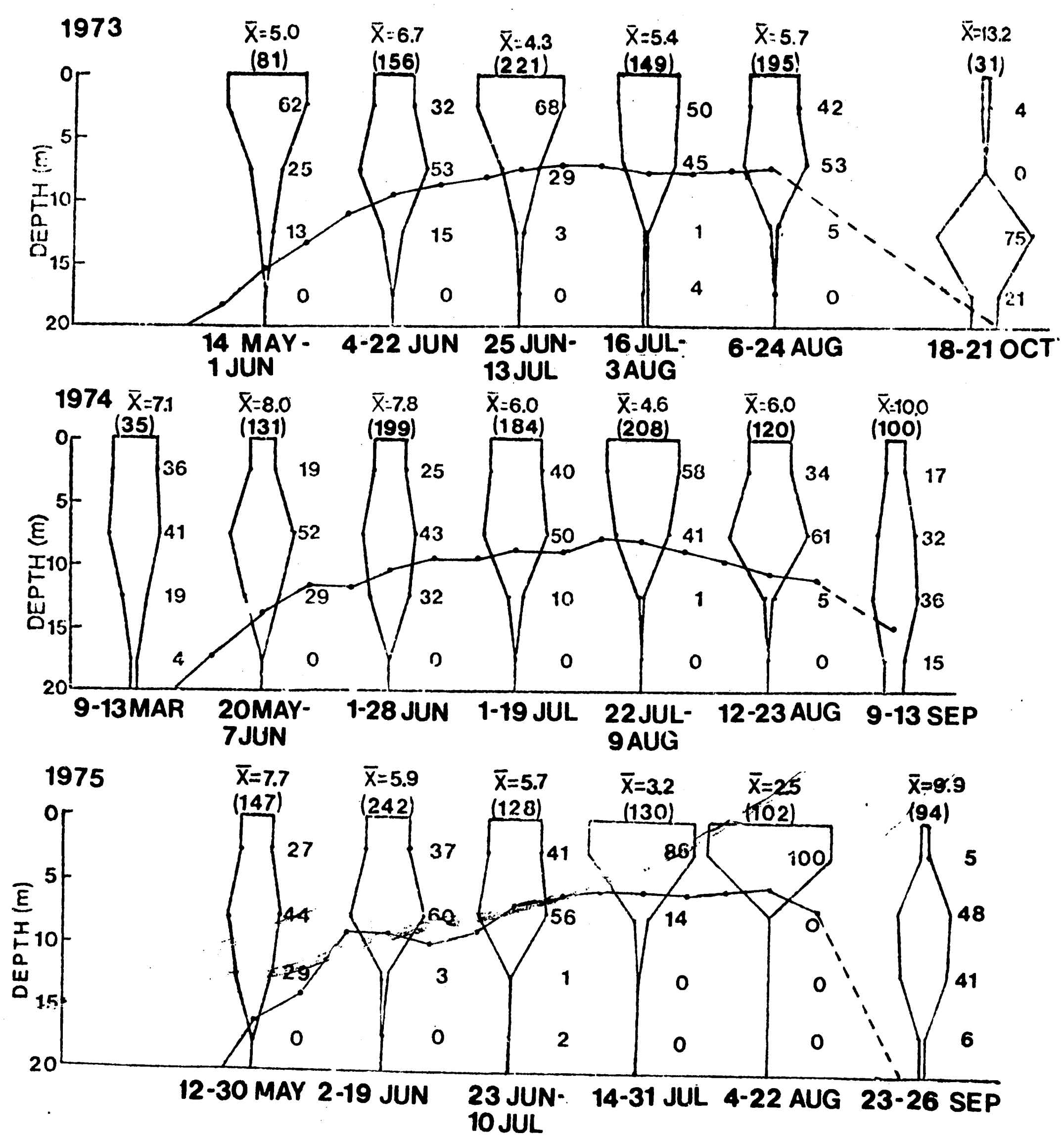
Differences in mean depth of capture between sites was examined by a two-way AOV test to test the hypothesis that the observed differences were within the expected range due to sampling error. There was not a significant difference ($P<.05$) between sites in 1973 or 1975, but there was a significant difference ($P<.01$) between sites in 1974 (Table 7). This difference was among all sites, not necessarily between the mixing site versus the control site.

The mean depth of capture of fish at site R, the experimental or site most likely to be affected by the mixing device, was compared to the combined mean from sites C, D and E, which represent the control area which would be least affected by mixing, using a weekly paired t-test (Table 8). There was not a significant difference ($P<.05$) between the control and experimental areas for any of the three years of study suggesting an absence of a local effect of the mixing device on the depth distribution of gizzard shad.

White Crappie (*Pomoxis annularis*)

White crappie were distributed to all depths during the March, 1974 sample (Figure 4). They abandoned the 15-20 m strata by late May-early June 1973-75, and during the summer they were rarely caught in the 15-20 m depth interval. By mid-summer (23 June thru 1 July) most crappies were caught in the upper 10 m of the lake. During August 1975 white crappie were caught only within the epilimnion (0-5 m interval). Each year the range in depth of white crappie was substantially greater after autumnal partial circulation when DO was distributed to deeper

Figure 4. Depth distribution of white crappie represented by polygons that approximate the percentage (shown alongside the polygons) of fish captured at each depth interval, in relation to the 2 mg/l DO isopleth (curve); the $\bar{X}$ represents the mean depth (m), and the value in ( ) the total adjusted number caught in that interval.


1973
DEPTH (m)
14 MAY-1 JUN
4-22 JUN
25 JUN-13 JUL
16 JUL-3 AUG
6-24 AUG
18-21 OCT
1974
9-13 MAR
20 MAY-7 JUN
1-28 JUN
1-19 JUL
22 JUL-9 AUG
12-23 AUG
9-13 SEP
1975
12-30 MAY
2-19 JUN
23 JUN-10 JUL
14-31 JUL
4-22 AUG
23-26 SEP

depths (Figure 4).

A weighted mean depth of capture was calculated each week for each site and for all sites combined (Table 9). Site E had a shallower total mean depth of capture than any other site for all three years. Each year a highly significant difference (P<.01) in depth of capture was obtained among weeks (Table 10). This indicates a changing depth distribution of white crappie over the summer period. The weekly paired t-test between years indicated no significant difference between 1973 vs. 1974 or between 1973 vs 1975, but there was a highly significant difference (P<.01) between 1974 vs. 1975 (Table 11). The average mean depth of capture was deeper in 1974 than in 1975 which corresponds with the available habitat data for those two years (Table 11).

In 1974 the correlations between white crappie mean depth of capture and the depths of the 4 and 6 mg/l DO isopleths were significant (P<.05), but the correlation was not significant for the 2 and 8 mg/l DO isopleths (Table 5). In 1975 the correlation between white crappie depth of capture and the depths of the 2, 4 and 6 mg/l DO isopleths was highly significant (P<.01). During most of the summer period of 1975 DO was a major variable influencing the depth distribution of white crappie. The difference in depth of capture among sites was significant each year (Table 10). The weekly paired t-test between areas (mixing site versus control sites) indicated a significant difference (P<.05) only in 1975 (Table 11). This indicates that for 1973 and 1974, the significant t-test obtained between sites (Table 10) was among the three control sites rather than between the three control sites and the mixing site. In 1975, however, when the volume of the hypolimnion was large, compared to 1974, the mean depth of capture

Table 9. Weekly mean depth of capture (m) of white crappie, 1973 thru 1975; sites C, D and E were from the control area, site R was close to the mixing device.

	March	May			June				July					August			Sept.		Oct.	Total
	12	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	11	24	19	mean
									1973											
Site C	-	7.5	10.5	--	7.1	6.7	5.9	2.9	5.3	3.6	8.5	3.6	7.2	8.8	8.3	8.5	-	-	12.5	7.0
Site D	-	8.5	7.5	8.6	10.2	7.7	8.0	3.1	3.9	4.8	4.8	6.2	6.0	5.9	4.4	5.4	-	-	12.5	6.7
Site E	-	2.5	4.0	2.5	2.5	4.2	4.4	2.5	2.5	4.4	4.6	4.8	4.8	5.0	6.5	2.9	-	-	11.4	4.3
Site R	-	3.7	3.8	3.5	4.5	7.5	6.5	2.5	5.4	4.9	3.0	2.5	9.1	5.2	7.2	7.5	-	-	14.8	5.7
Combined	-	4.3	6.3	5.0	7.2	6.4	6.4	2.9	4.9	4.6	5.6	4.1	7.2	6.7	6.6	6.4	-	-	13.2	6.1
									1974											
Site C	8.4	-	9.9	5.7	6.9	7.8	11.0	7.7	11.0	5.9	5.9	4.9	2.5	10.0	7.0	6.9	8.2	-	-	7.5
Site D	8.6	-	7.5	6.6	11.3	6.5	7.5	7.5	7.5	7.5	5.1	6.8	5.0	7.5	7.5	7.5	11.2	-	-	7.6
Site E	5.5	-	7.5	6.5	--	7.5	3.3	11.4	2.5	2.5	3.7	2.5	2.5	2.5	2.5	3.7	8.2	-	-	5.0
Site R	4.5	-	8.8	7.1	4.6	5.9	6.5	6.3	5.1	6.7	5.9	2.7	5.2	4.6	6.5	7.0	11.2	-	-	6.2
Combined	7.1	-	9.5	6.7	7.3	6.9	9.3	6.3	7.8	6.1	5.0	4.3	4.8	5.3	5.9	6.1	10.0	-	-	6.8
									1975											
Site C	-	9.1	6.4	7.5	5.8	3.6	2.5	7.5	2.5	2.5	3.9	2.5	3.1	2.5	2.5	2.5	-	10.9	-	4.7
Site D	-	8.1	2.5	5.6	2.5	7.6	6.6	3.8	17.5	--	2.5	5.3	3.6	2.5	2.5	--	-	9.8	-	5.4
Site E	-	2.5	4.9	4.2	4.7	3.8	4.9	2.5	--	2.5	2.5	2.5	2.5	2.5	2.5	2.5	-	7.9	-	3.6
Site R	-	9.2	9.0	6.4	7.3	7.6	7.2	7.5	4.8	7.2	3.6	5.0	3.1	2.5	2.5	2.5	-	11.0	-	6.0
Combined	-	8.7	7.5	6.4	6.0	4.8	6.2	7.0	5.6	3.9	3.3	3.1	3.2	2.5	2.5	2.5	-	9.9	-	5.2

\- Indicates no sampling for that date

-- Indicates that sampling was conducted but white crappie were not captured

Table 10. Summary of two-way analysis of variance comparison of average depth of capture of white crappie (df = degrees of freedom, SS = sum of squares, MS = mean square).

Source of variation	df	SS	MS	F
		1973		
Weeks	15	262.05	17.47	5.18**
Sites	3	69.00	23.0	6.82**
Error	45	151.65	3.37	
		1974		
Weeks	15	143.55	9.57	2.93**
Sites	3	70.11	23.37	7.15**
Error	45	147.15	3.27	
		1975		
Weeks	15	263.85	17.59	3.36**
Sites	3	49.80	16.60	3.17*
Error	45	235.35	5.23	

$^{*}F_{.05}[3, 45] = 2.82$

$^{**}F_{.01}[3, 45] = 4.27$; $[15, 45] = 2.48$

Table 11. Summary of t-test comparisons between average depth of capture of white crappie at sites C, D, and E combined versus site R and between years using the combined sites depth distributions.

Site	Average mean depth	Standard deviation	df	t-value
		1973		
C,D.E	6.03	1.98	15	0.58
R	5.72	3.12		
		1974		
C,D,E	6.73	1.82	14	0.81
R	6.27	1.95		
		1975		
C,D,E	4.66	2.34	15	-2.33*
R	6.02	2.62		
	1973 vs. 1974			
1973 combined	5.73	1.26	13	-1.59
1974 combined	6.52	1.55		
	1973 vs. 1975			
1973 combined	5.64	1.27	14	1.06
1975 combined	4.88	2.03		
	1974 vs. 1975			
1974 combined	6.52	1.55	13	6.10**
1975 combined	4.60	1.80		

*Significant at P = .05

**Significant at P = .01

of fish at the control sites was 4.66 m, substantially less than in previous years and statistically different from the mixing site. The depth of capture was greater at the mixing site indicating a possible response to the mixing or more likely a deeper distribution in the early summer when DO was at higher concentrations in deeper water at the mixing site before the mixing device was operating.

Freshwater Drum (Aplodinotus grunniens)

Freshwater drum were captured at all depth intervals in the early summer period (12 May to 7 June) during all three years (Figure 5). By mid-summer (23 June to 1 July) drum had almost completely abandoned the 15-20 m interval, and through the entire three years, only one freshwater drum was captured in the 15-20 m interval between 23 June and 24 August. In 1974 and 1975 drum were captured only in the upper 10 m of the lake between 14 July and 23 August; in 1975 only 1 drum was captured in a net set deeper than 5 m between 14 July and 22 August. Freshwater drum were captured in deeper water in fall collections during autumnal partial circulation. Seasonal changes in depth of capture of drum indicated that they were highly responsive to DO conditions which develop during summer stagnation (Figure 5).

A weekly mean depth distribution was calculated for each site although during mid to late-summer there were 22 weeks when drum were not captured at a specific site (Table 12). There was not a single site which was consistently deeper or shallower than the other sites over all three years of study. The depth of freshwater drum was extremely shallow during July and August, 1975.

The AOV test indicated a highly significant difference ($P<.01$)

Figure 5. Depth distribution of freshwater drum represented by polygons that approximate the percentage (shown alongside the polygon) of fish captured at each depth interval, in the relation to the 2 mg/l DO isopleth (curve); the $\bar{X}$ represents the mean depth (m), and the value in ( ) the total adjusted number caught in that interval.

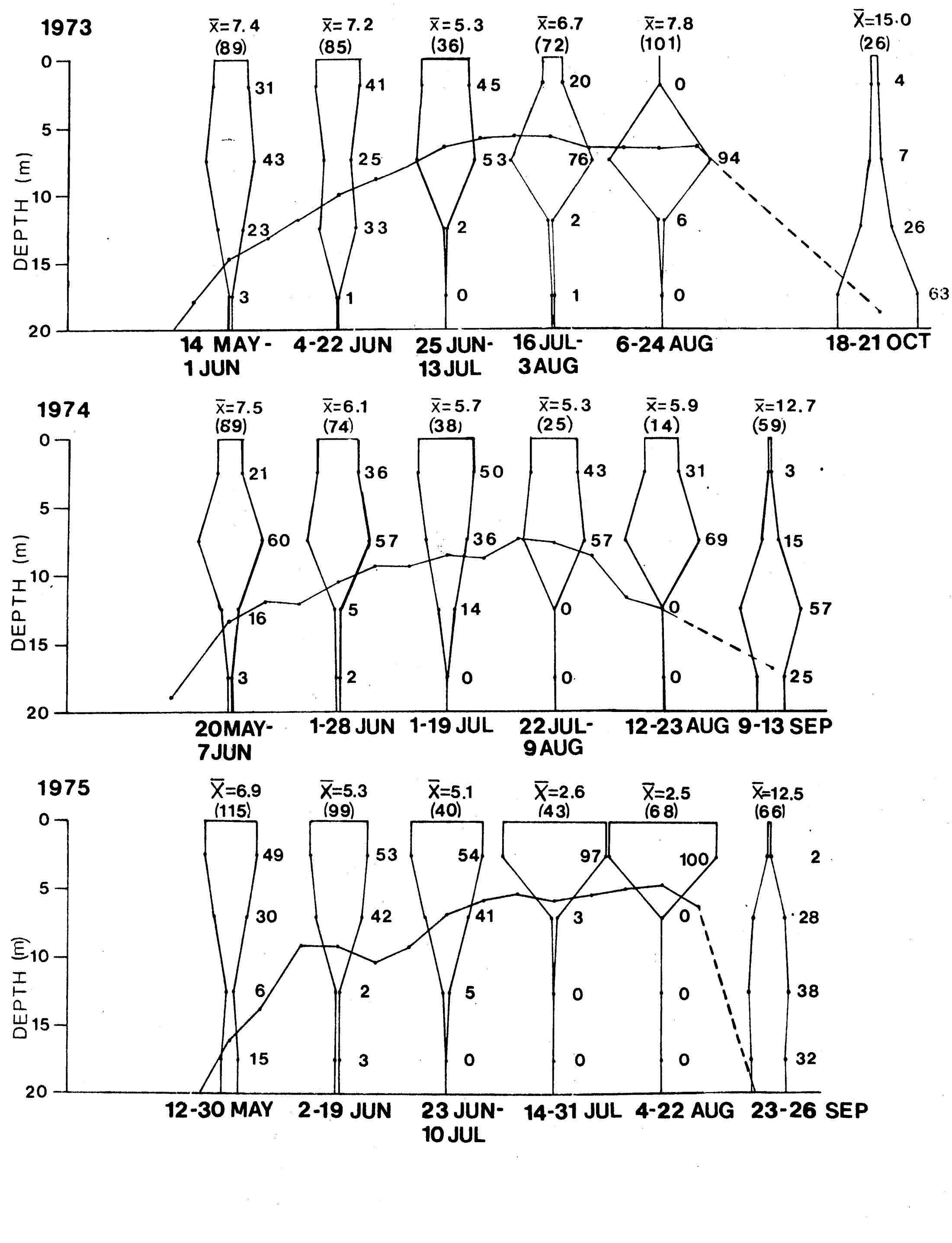

1973
X̄=7.4
(89)
X̄=7.2
(85)
X̄=5.3
(36)
X̄=6.7
(72)
X̄=7.8
(101)
X̄=15.0
(26)
DEPTH (m)
0
5
10
15
20
31
43
23
3
41
25
33
1
45
53
2
0
20
76
2
1
0
94
6
0
4
7
26
63
14 MAY-
1 JUN
4-22 JUN
25 JUN-
13 JUL
16 JUL-
3 AUG
6-24 AUG
18-21 OCT
1974
X̄=7.5
(69)
X̄=6.1
(74)
X̄=5.7
(38)
X̄=5.3
(25)
X̄=5.9
(14)
X̄=12.7
(59)
21
60
16
3
36
57
5
2
50
36
14
0
43
57
0
0
31
69
0
0
3
15
57
25
20MAY-
7JUN
1-28 JUN
1-19 JUL
22 JUL-
9 AUG
12-23 AUG
9-13 SEP
1975
X̄=6.9
(115)
X̄=5.3
(99)
X̄=5.1
(40)
X̄=2.6
(43)
X̄=2.5
(68)
X̄=12.5
(66)
49
30
6
15
53
42
2
3
54
41
5
0
97
3
0
0
100
0
0
0
2
28
38
32
12-30 MAY
2-19 JUN
23 JUN-
10 JUL
14-31 JUL
4-22 AUG
23-26 SEP

Table 12. Weekly mean depth of capture (m) of freshwater drum, 1973 thru 1975; sites C, D and E were from the control area, site R was close to the mixing device.

	March	May			June				July					August			Sept.		Oct.	Total
	12	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	11	24	19	mean
										1973										
Site C	-	8.3	7.5	2.5	7.5	--	6.5	7.5	5.9	4.7	8.2	7.5	9.0	11.1	11.1	10.4	-	-	15.7	8.2
Site D	-	7.7	7.9	7.5	11.6	10.2	11.5	5.2	7.5	7.6	6.6	6.2	7.1	7.5	--	--	-	-	13.7	8.7
Site E	-	2.5	6.1	4.1	2.5	7.5	3.3	4.4	--	4.4	5.8	6.3	6.3	--	--	--	-	-	15.9	6.6
Site R	-	8.2	5.8	12.3	4.7	7.5	2.5	2.5	7.5	3.6	7.5	6.4	9.1	8.2	9.2	7.5	-	-	13.1	7.2
Combined	-	7.6	7.0	7.8	6.6	7.6	7.4	4.8	6.4	5.1	6.9	6.5	7.9	9.7	10.9	10.1	-	-	14.7	7.9
										1974										
Site C	7.5	-	9.1	7.5	2.5	5.8	6.9	9.3	7.5	3.4	5.1	7.5	--	--	6.6	--	11.6	-	-	6.7
Site D	--	-	7.0	5.9	7.5	7.5	5.0	7.5	9.3	--	5.0	7.5	7.5	7.5	7.5	7.5	16.5	-	-	7.5
Site E	--	-	5.6	4.1	2.5	2.5	3.7	2.5	7.5	2.5	2.5	--	3.9	2.5	--	--	15.3	-	-	5.2
Site R	--	-	8.7	9.4	10.4	6.6	7.5	5.5	8.7	5.0	2.5	5.9	5.8	5.1	5.8	7.5	7.8	-	-	6.8
Combined	7.5	-	7.6	7.4	8.0	5.6	5.0	5.3	8.5	4.1	4.0	6.3	5.3	4.2	6.5	7.5	12.6	-	-	6.6
										1975										
Site C	-	6.3	6.5	5.9	5.4	3.8	4.0	--	2.5	--	--	2.5	2.5	2.5	2.5	2.5	-	--	-	4.5
Site D	-	6.2	3.3	2.5	2.5	3.9	6.1	2.5	2.5	--	2.5	2.5	3.6	2.5	2.5	--	-	2.5	-	3.2
Site E	-	2.5	12.5	4.3	2.5	2.5	6.2	2.5	4.4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	-	8.0	-	3.9
Site R	-	12.8	9.7	7.8	6.9	12.7	7.5	8.2	2.5	4.2	2.5	--	2.5	2.5	--	--	-	13.7	-	6.3
Combined	-	8.5	6.2	5.7	4.6	5.1	6.5	6.3	3.4	3.5	2.5	2.5	2.8	2.5	2.5	2.5	-	12.5	-	4.8

- Indicates no sampling for that date

-- Indicates that sampling was conducted but freshwater drum were not captuted among weeks during each year of study (Table 13). This suggests a changing depth distribution over the summer period. The difference in mean depth of capture between 1973 vs. 1974 was significant (P<.05) and the difference between 1973 vs. 1975 and 1974 vs. 1975 was highly significant (P<.01) (Table 14). The mean depth of capture was less in 1975 than in 1973 or 1974, concurrently, the depth of the 2 mg/1 DO isopleth was less in 1975 than in 1973 or 1974 (Figure 2).

There was a significant correlation (P<.05) between the weekly mean depth of capture of freshwater drum and the 6 mg/1 DO isopleth in 1974 (Table 5). In 1975, there was a highly significant (P<.01) correlation between mean depth of capture and the 2, 4 and 6 mg/1 DO isopleths. The level of the anoxic hypolimnion was closer to the surface in 1975 than in 1973 and 1974. The degree of DO depletion in 1975 had a pronounced effect on the depth distribution of drum in that year, indicated by the high correlation between depth of capture and DO (Figures 2 and 5). It is apparent from the analyses that the depth distribution of freshwater drum is highly influenced by DO.

The AOV test indicated a significant difference in mean depth of capture among sites in all three years (Table 13). A paired t-test indicated a significant difference between the experimental and control areas only for 1975 (Table 14). This appears to indicate a possible effect from the pump, but examination of the weekly depth of capture data (Table 12) reveals that much of this difference occurrs early in the summer before the pumping operation started. The explanation for this is the same as for white crappie, i.e., differing levels of DO isopleths at the two areas.

Table 13. Summary of two-way analysis of variance comparison of average depth of capture of freshwater drum (df = degrees of freedom, SS = sum of squares, MS = mean square).

Source of variation	df	SS	MS	F
		1973		
Weeks	15	343.05	22.87	5.15**
Sites	3	40.71	13.57	3.06*
Error	45	199.80	4.44	
		1974		
Weeks	15	266.55	17.77	5.23**
Sites	3	46.80	15.60	4.59**
Error	45	153.00	3.40	
		1975		
Weeks	15	282.95	18.86	3.73**
Sites	3	83.79	27.93	5.52**
Error	45	227.70	5.06	

$^*F_{.05}[3, 45] = 2.82$

$^{**}F_{.01}[3, 45] = 4.27$; $[15, 45] = 2.48$

Table 14. Summary of t-test comparisons between average depth of capture of freshwater drum at sites C, D, and E combined versus site R and between years using the combined sites depth distributions.

Site	Average mean depth	Standard deviation	df	t-value
		1973		
C,D.E	7.88	2.58	15	0.93
R	7.22	3.01		
		1974		
C,D,E	6.44	2.65	14	-0.50
R	6.81	2.03		
		1975		
C,D,E	3.80	1.50	12	-3.50*
R	7.19	4.17		
		1973 vs. 1974		
1973 combined	7.47	1.75	13	2.36*
1974 combined	6.09	1.52		
		1973 vs. 1975		
1973 combined	7.48	1.69	14	4.09**
1975 combined	4.34	1.93		
		1974 vs. 1975		
1974 combined	6.09	1.52	13	3.75**
1975 combined	4.04	1.61		

*Significant at P = .05

**Significant at P = .01

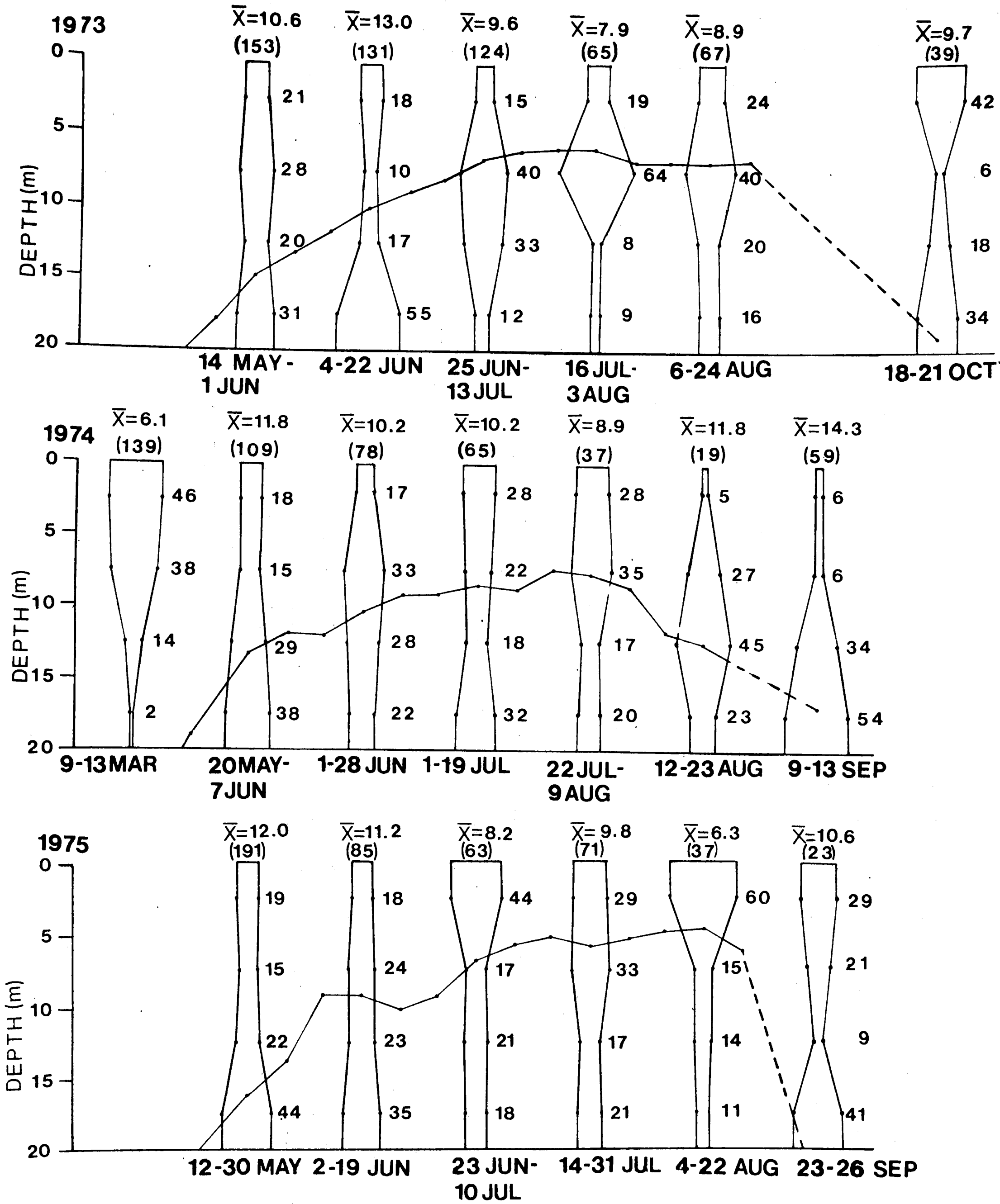
Black Bullhead (*Ictalurus melas*)

Black bullheads were captured at all depths during the entire summer (Figure 6). They were more abundant in shallower water in the one week of sampling in early spring (9-13 March 1974) than in any other weekly collection. Bullheads were obviously highly tolerant to low oxygen as there was a high frequency of capture at depths in the anoxic hypolimnion; however, their mean depth of capture did decrease as the anoxic hypolimnion expanded, but they never abandoned the deeper intervals completely. The bullhead could not live continuously in the anoxic hypolimnion, as most of the fish in those nets were dead. Their presence in the anoxic strata is presumed to be the result of feeding forays. Bullhead were captured at a greater mean depth when DO was available throughout the water column.

In all three years, the weekly mean depth of capture of black bullhead was consistently deeper than any other species (Table 15). The difference in mean depth of capture among weeks in 1974 was significant, but the difference among weeks in 1973 and 1975 was not significant (Table 16). This suggests a fairly constant depth distribution over the summer period in 1973 and 1975. The paired t-test of depth of capture between years was not significant ($P<.05$) which again tends to indicate a constant annual cycle of depth distribution for the black bullhead (Table 17).

There was not a significant correlation between the mean depth of capture of black bullheads and the selected DO isopleths in 1974 (Table 5). In 1975, when DO was more limiting (Table 1), there was a highly significant correlation ($P<.01$) between bullhead depth of cap-

Figure 6. Depth distribution of black bullhead represented by polygons that approximate the percentage (shown alongside the polygons) of fish captured at each depth interval, in relation to the 2 mg/l DO isopleth (curve); the $\bar{X}$ represents the mean depth (m), and the value in ( ) the total adjusted number caught in that interval.



1973
X̄=10.6 (153)
X̄=13.0 (131)
X̄=9.6 (124)
X̄=7.9 (65)
X̄=8.9 (67)
X̄=9.7 (39)
DEPTH (m)
0
5
10
15
20
21 28 20 31
18 10 17 55
15 40 33 12
19 64 8 9
24 40 20 16
42 6 18 34
14 MAY-1 JUN
4-22 JUN
25 JUN-13 JUL
16 JUL-3 AUG
6-24 AUG
18-21 OCT
1974
X̄=6.1 (139)
X̄=11.8 (109)
X̄=10.2 (78)
X̄=10.2 (65)
X̄=8.9 (37)
X̄=11.8 (19)
X̄=14.3 (59)
46 38 14 2
18 15 29 38
17 33 28 22
28 22 18 32
28 35 17 20
5 27 45 23
6 6 34 54
9-13 MAR
20 MAY-7 JUN
1-28 JUN
1-19 JUL
22 JUL-9 AUG
12-23 AUG
9-13 SEP
1975
X̄=12.0 (191)
X̄=11.2 (85)
X̄=8.2 (63)
X̄=9.8 (71)
X̄=6.3 (37)
X̄=10.6 (23)
19 15 22 44
18 24 23 35
44 17 21 18
29 33 17 21
60 15 14 11
29 21 9 41
12-30 MAY
2-19 JUN
23 JUN-10 JUL
14-31 JUL
4-22 AUG
23-26 SEP

Table 15. Weekly mean depth of capture (m) of black bullhead, 1973 thru 1975; sites C, D and E were from the control area, site R was close to the mixing device.

	March	May			June				July					August			Sept.		Oct.	Total
	12	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	11	24	19	mean
										1973										
Site C	-	8.3	9.1	10.2	12.6	7.0	10.0	12.6	7.5	8.3	11.0	8.1	11.2	7.5	10.4	8.5	-	-	9.9	9.5
Site D	-	11.2	8.0	11.4	4.5	13.7	9.6	10.8	8.6	7.5	7.5	7.5	5.8	7.5	4.6	--	-	-	9.0	8.6
Site E	-	8.7	11.2	14.8	14.7	14.5	13.6	9.5	9.6	6.3	6.3	6.2	7.0	7.6	5.3	5.1	-	-	12.8	9.6
Site R	-	4.4	13.8	17.5	16.1	15.5	12.5	12.5	9.8	15.0	13.9	13.4	9.9	9.6	11.8	13.8	-	-	8.2	12.4
Combined	-	8.1	10.4	11.4	13.6	13.1	11.1	11.0	9.5	8.5	9.5	8.2	9.9	8.6	7.8	10.4	-	-	9.7	10.0
										1974										
Site C	3.9	-	11.4	10.0	4.1	10.3	9.2	12.5	9.2	14.1	6.3	11.4	15.0	12.5	17.5	9.9	14.5	-	-	10.7
Site D	8.2	-	11.8	8.0	7.6	8.6	4.1	2.5	4.5	7.5	11.2	17.5	9.2	7.5	11.4	--	11.1	-	-	8.9
Site E	7.3	-	7.6	10.1	10.1	8.3	10.9	10.5	6.1	13.0	10.1	4.2	5.8	--	7.5	11.2	14.6	-	-	8.8
Site R	5.5	-	16.3	13.6	16.0	10.6	11.5	7.6	14.8	11.5	11.2	6.6	--	12.5	--	15.8	17.5	-	-	12.0
Combined	6.2	-	12.9	10.8	11.5	9.7	9.5	10.0	7.8	12.6	9.7	7.8	9.4	11.4	12.1	11.8	14.4	-	-	10.1
										1975										
Site C	-	16.2	12.2	14.0	15.1	12.1	9.4	10.4	17.5	12.1	13.4	8.4	10.1	12.5	12.5	7.5	-	10.2	-	12.1
Site D	-	10.2	12.5	9.0	7.8	6.3	12.2	17.5	2.5	2.5	5.8	4.4	7.5	--	2.5	2.5	-	2.5	-	7.2
Site E	-	10.1	9.9	12.4	10.7	8.7	9.8	11.6	14.2	5.0	8.1	5.4	14.2	3.7	10.0	3.3	-	4.5	-	8.8
Site R	-	14.3	14.8	13.4	12.9	12.6	11.5	--	17.5	14.2	9.8	10.8	7.5	12.6	7.5	12.5	-	16.2	-	12.5
Combined	-	12.8	11.4	12.2	12.3	11.1	10.4	11.4	8.7	6.1	9.3	8.1	10.6	6.4	6.7	5.9	-	10.6	-	9.6

- Indicates no sampling for that date

-- Indicates that sampling was conducted but black bullhead were not captured

Table 16. Summary of two-way analysis of variance comparison of average depth of capture of black bullhead (df = degrees of freedom, SS = sum of squares, MS = mean square).

Source of variation	df	SS	MS	F
		1973		
Weeks	15	177.45	11.83	1.68
Sites	3	126.90	42.30	6.00**
Error	45	317.25	7.05	
		1974		
Weeks	15	370.35	24.69	2.61**
Sites	3	114.51	38.17	4.04*
Error	45	425.25	9.45	
		1975		
Weeks	15	219.00	14.6	1.42
Sites	3	316.50	105.5	10.30**
Error	45	460.80	10.24	

*$F_{.05}[3, 45] = 2.82$

**$F_{.01}[3, 45] = 4.27$; $[15, 45] = 2.48$

Table 17. Summary of t-test comparisons between average depth of capture of black bullhead at sites C, D, and E combined versus site R and between years using the combined sites depth distributions.

Site	Average mean depth	Standard deviation	df	t-value
		1973		
C,D,E	9.16	1.81	15	-3.74**
R	12.35	3.32		
		1974		
C,D,E	9.39	1.93	13	-2.88*
R	12.21	3.75		
		1975		
C,D,E	9109	2.50	14	-3.70**
R	12.54	2.83		
	1973 vs. 1974			
1973 combined	10.21	1.73	13	-0.44
1974 combined	10.50	1.63		
	1973 vs. 1975			
1973 combined	10.07	1.76	14	0.96
1975 combined	9.56	2.42		
	1974 vs. 1975			
1974 combined	10.66	1.69	13	1.41
1975 combined	9.56	2.43		

*Significant at P = .05

**Significant at P = .01

ture and the 2, 4 and 6 mg/l DO isopleths (Table 6). DO influences the depth distribution of black bullheads, but to a lesser degree than for other species.

The AOV test indicated a significant difference in depth of capture among sites in all three years (Table 16). The weekly paired t-test between the experimental and control areas indicated a significant difference between the areas in all three years (Table 17). In each case, the mixing site was significantly deeper than the control sites. Examination of the data reveals this phenomenon occurring in the early summer before the pump was in operation which tends to discount the possibility that the mixing was responsible for the increased depth of capture at site R (Table 15).

Channel Catfish (*Ictaluris punctatus*)

Channel catfish were distributed to all depths of the lake during the early summer period (12 May thru 7 June) in each year of study (Figure 7). They gradually began to abandon the deeper depths as the anoxic hypolimnion expanded, but channel catfish were occasionally captured at the deeper depths throughout most of the summer. In 1974 and 1975, channel catfish were not found below 10 m during the last three weeks of the summer study (4-23 August). The mean depth of capture was substantially deeper during autumnal partial circulation in three years when adequate DO was available at deeper depths.

The mean depth of capture of channel catfish is more shallow at site D in 1973 and 1975 than at any other site (Table 18). The AOV test indicated a highly significant difference (P<.01) among weeks for each year of study which suggests a changing distribution over the

Figure 7. Depth distribution of channel catfish represented by polygons that approximate the percentage (shown alongside the polygons) of fish captured at each depth interval, in relation to the 2 mg/l DO isopleth (curve); the $\bar{X}$ represents the mean depth (m), and the value in ( ) the total adjusted number caught in that interval.

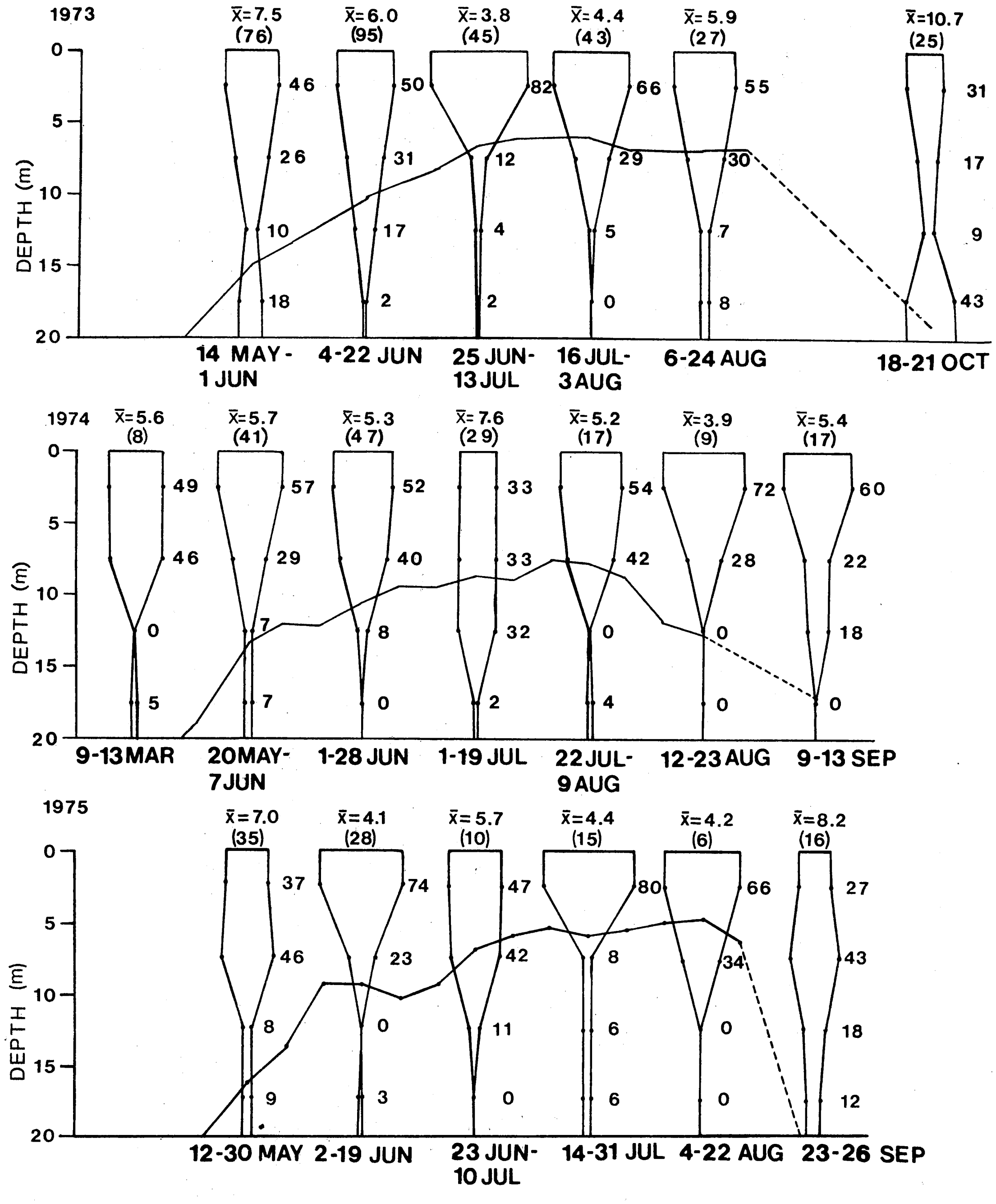

1973
x̄=7.5 (76)
x̄=6.0 (95)
x̄=3.8 (45)
x̄=4.4 (43)
x̄=5.9 (27)
x̄=10.7 (25)
DEPTH (m)
14 MAY-1 JUN
4-22 JUN
25 JUN-13 JUL
16 JUL-3 AUG
6-24 AUG
18-21 OCT
1974
x̄=5.6 (8)
x̄=5.7 (41)
x̄=5.3 (47)
x̄=7.6 (29)
x̄=5.2 (17)
x̄=3.9 (9)
x̄=5.4 (17)
9-13 MAR
20 MAY-7 JUN
1-28 JUN
1-19 JUL
22 JUL-9 AUG
12-23 AUG
9-13 SEP
1975
x̄=7.0 (35)
x̄=4.1 (28)
x̄=5.7 (10)
x̄=4.4 (15)
x̄=4.2 (6)
x̄=8.2 (16)
12-30 MAY
2-19 JUN
23 JUN-10 JUL
14-31 JUL
4-22 AUG
23-26 SEP

Table 18. Weekly mean depth of capture (m) of channel catfish, 1973 thru 1975; sites C, D and E were from the control area, site R was close to the mixing device.

	March	May			June				July					August			Sept.		Oct.	Total
	12	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	11	24	19	mean
									1973											
Site C	-	7.9	3.6	9.5	5.5	4.0	5.1	4.0	4.5	5.1	5.1	2.5	7.6	6.3	5.1	8.5	-	-	10.9	6.0
Site D	-	7.2	4.9	3.6	7.2	7.8	6.9	2.5	2.5	2.5	4.0	4.5	3.9	2.5	2.5	7.5	-	-	9.0	4.9
Site E	-	7.5	8.6	10.4	9.2	7.4	4.1	2.5	2.5	5.0	5.0	5.0	3.6	2.5	--	--	-	-	14.0	6.3
Site R	-	13.0	4.9	7.3	6.1	6.2	2.5	--	4.1	--	3.7	4.9	4.1	5.0	7.5	2.5	-	-	9.0	5.5
Combined	-	10.1	5.0	7.9	7.1	6.5	4.9	3.3	3.9	3.9	4.3	4.1	5.0	4.5	4.6	8.8	-	-	10.7	5.9
									1974											
Site C	5.1	-	4.9	5.7	2.5	3.7	7.3	6.8	11.2	--	7.0	9.7	2.5	--	7.5	5.0	6.8	-	-	6.1
Site D	2.5	-	4.2	5.0	7.5	4.1	5.0	5.0	--	5.0	7.5	--	4.2	--	--	2.5	5.9	-	-	5.2
Site E	7.5	-	5.0	7.5	--	2.5	2.5	5.0	7.5	--	2.5	--	2.5	2.5	2.5	--	2.5	-	-	5.0
Site R	5.5	-	8.8	2.5	5.0	2.5	5.8	6.2	10.9	12.4	2.5	7.5	2.5	2.5	2.5	7.5	3.8	-	-	5.5
Combined	5.6	-	6.4	4.6	6.0	3.5	6.0	6.3	9.7	9.5	6.0	9.1	3.0	2.5	4.2	5.0	5.6	-	-	5.8
									1975											
Site C	-	--	5.2	7.5	2.5	5.7	2.5	--	7.5	--	2.5	--	2.5	4.2	--	2.5	-	9.0	-	5.3
Site D	-	11.9	2.5	4.3	--	3.7	2.5	9.3	--	2.5	2.5	2.5	2.5	--	2.5	--	-	2.5	-	4.2
Site E	-	4.9	--	5.0	7.5	--	4.1	--	7.5	2.5	2.5	--	10.0	--	-	--	-	7.5	-	5.6
Site R	-	11.2	7.5	4.9	2.5	2.5	5.1	--	--	--	--	7.3	2.5	--	7.5	--	-	9.5	-	5.6
Combined	-	9.9	5.4	5.4	3.2	4.8	3.8	9.3	7.5	2.5	2.5	6.2	4.3	4.2	5.1	2.5	-	8.3	-	5.3

- Indicates no sampling for that date

-- Indicates that sampling was conducted but channel catfish were not captured summer period (Table 19). The paired t-test between years revealed a lack of any significant difference in depth of capture between any of the years (Table 20).

There was not a significant correlation between the mean depth of capture of channel catfish and the selected DO isopleths in 1974 (Table 6). In 1975, there was a significant correlation ($P<.05$) between depth of capture and the 2 mg/l DO isopleth. It appears that channel catfish are not highly influenced by stratification and anoxic conditions, probably because their normal mean depth distribution is above the level of the anoxic water.

The AOV test did not indicate a significant difference ($P<.05$) among sites for any of the years of depth of capture data (Table 19). The paired t-test between the mixing and control areas also did not reveal any significant differences which suggests a uniform distribution over the entire lake and a lack of any local effects created by the mixing device (Table 20).

Table 19. Summary of two-way analysis of variance comparison of average depth of capture of channel catfish (df = degrees of freedom, SS = sum of squares, MS = mean square).

Source of variation	df	SS	MS	F
		1973		
Weeks	15	275.70	18.38	5.30**
Sites	3	16.50	5.50	1.58
Error	45	156.15	3.47	
		1974		
Weeks	15	269.10	17.94	4.98**
Sites	3	11.19	3.73	1.04
Error	45	162.00	3.60	
		1975		
Weeks	15	292.65	19.51	5.70**
Sites	3	21.39	7.13	2.08
Error	45	153.90	3.42	

**$F_{.01}[15, 45] = 2.48$

Table 20. Summary of t-test comparisons between average depth of capture of channel catfish at sites C, D, and E combined versus site R and between years using the combined sites depth distributions.

Site	Average mean depth	Standard deviation	df	t-value
		1973		
C,D,E	5.89	2.20	13	0.17
R	5.77	2.79		
		1974		
C,D,E	5.25	1.94	15	-0.38
R	5.52	3.19		
		1975		
C,D,E	4.68	1.84	9	-1.42
R	6.05	3.05		
	1973 vs. 1974			
1973 combined	5.27	1.65	13	-0.64
1974 combined	5.84	2.30		
	1973 vs. 1975			
1973 combined	5.59	2.20	14	0.64
1975 combined	5.10	2.31		
	1974 vs. 1975			
1974 combined	5.84	2.30	13	1.49
1975 combined	4.76	1.96		

CHAPTER IV

SUMMARY AND CONCLUSIONS

When this study was planned, it was assumed that the pumping device would destratify the lake for the entire summer, but this did not occur. According to previous temperature and DO measurements, 1973 appeared to be a normal year with little change in the lake stratification pattern. In 1974, there was a local increase in available fish habitat during the late summer and the lake entered autumnal partial circulation at an earlier date. In 1975, there was a decrease in available fish habitat in the summer because of pronounced chemical stratification, but again the lake entered autumnal partial circulation at an earlier date.

The statistical analyses of the depth of capture for all five species indicated a significant difference among weeks in three of five species in 1973 and four of five species in 1974 and 1975. This indicates that most species change their depth distribution during the year in response to temporal changes in some environmental variable.

There was a significant difference among sites in three of five species in 1973 and 1975, and for four of five species in 1974. This suggests a variable depth distribution among the sites due to actual differences between the sites or to sampling variation created by small sample sizes. There was a significant difference between the mixing site (R) and the unmixed sites (C, D and E) in one of five species in

1973 and 1974, and in three of five species in 1975. This difference was shown to occur in the early summer before pumping operations commenced and to probably be a result of the different levels of DO isopleths which occur at the two areas in the early summer rather than an effect of the pumping device.

There was a significant difference between depth of capture in 1973 vs. 1974, and 1973 vs. 1975 in one of five species. There was a significant difference between 1974 vs. 1975 in two of five species in which the 1974 depth of capture was deeper for both species. This coincides with the habitat analysis which indicated more available habitat in 1974 than in 1975.

The weekly mean depth of capture was related to at least one DO isopleth for two of five species in 1974 and for all five species in 1975 (Table 6). The depth of capture generally decreased as the anoxic hypolimnion expanded upward, and increased when DO was available at all intervals. It is evident that fish depth distribution in Arbuckle Lake was related to thermal and especially to chemical stratification.

This conclusion that DO controls the depth distribution of fish during summer stratification agrees with the basic findings of Dendy (1945), Fast (1968), Mayhew (1963) and others. Hover (1976) concluded that the feeding habits of the fishes studied were probably more responsible for the vertical distributions observed than temperature or DO requirements. The reason for this lack of agreement among studies is simply the result of different distributions of DO in different study lakes. In Arbuckle Lake, the depth of the anoxic hypolimnion during summer stratification is usually 6-8 m while other lakes have much deeper levels of adequate DO which allows other factors to control distribution.

Black bullhead were quite tolerant of low DO conditions and maintained the deepest depth distribution. Gizzard shad and channel catfish maintained a midwater distribution and did not have to readjust greatly during summer stratification. Freshwater drum and white crappie were most sensitive and obviously affected by stratification. They substantially altered their depth distributions during conditions of summer stratification and oxygen depletion. All species were influenced by reductions in available habitat which forced them closer to the surface. They were captured in deeper water during autumnal partial circulation when there was a redistribution of DO to all depths.

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