FISH DISTRIBUTION IN KEYSTONE RESERVOIR IN RELATION TO PHYSICOCHEMICAL STRATIFICATION

By

NEIL ENOCH CARTER

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1961

Submitted to the faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1967

FISH DISTRIBUTION IN KEYSTONE RESERVOIR IN
RELATION TO PHYSICOCHEMICAL
STRATIFICATION

Thesis Approved:

Troy C. Dorris
Thesis Adviser

Rudolph J. Miller

Roy W. Jones

N N Durham
Dean of the Graduate College

PREFACE

The objectives of the present study were to determinate vertical fish distributions in relation to limnological factors in Keystone Reservoir, and to field test sampling apparatus. New designs for portable float units and net rollers were tested. The vertical latin-square net was compared statistically to a modified net design created for open-water sampling.

Dr. Troy C. Dorris served as major adviser. Drs. Rudolph J. Miller and Roy W. Jones served on the advisory committee and criticized the manuscript. Dr. David Bee wrote the computer program for analyses of vertical distribution of fishes in relation to physicochemical stratification. Rex L. Eley helped make field collections.

This study was supported by funds granted by the Oklahoma Department of Wildlife Conservation through the Oklahoma Fish and Game Council, the Oklahoma Oil Refiner's Waste Control Council, and the Water Resources Research Institute, Oklahoma State University.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A study of fish distribution in Keystone Reservoir, Oklahoma, was made to help design future fishery investigations in this impoundment. Fish distribution patterns may be used in determination of fish-producing capacities of the reservoir, life histories of the species present, preferred habitat of juvenile and adult fishes at different times of the year, and the prediction of fish distribution for improved fishing success.

Several investigations on Norris Reservoir, Tennessee, have been made. Wiebe (1941) suggested that density currents influenced fish distribution. Dendy (1945) found temperature to be the most significant factor in influencing fish distribution. Haslbauer (1945) showed that sauger, walleye, largemouth bass, spotted bass, smallmouth bass, drum and carp tend to concentrate near the bottom while channel catfish and shad were not closely associated with the bottom. Cady (1945) observed that fishes there tend to vary widely in their depth distribution.

In Wheeler Reservoir, Alabama, Bryan and Howell (1946) believed that depth distribution of fishes (game, pan, food and rough fish) depended on other factors beside temperature, since temperature conditions were uniform. Fishes also had an unexplained tendency to avoid the bottom.

Loomis and Irwin (1954) found that depth distribution of fishes in Lake Carl Blackwell, Oklahoma, was not related to temperature, since temperature conditions were uniform. Hancock (1954) established that warm water entering the Canton Reservoir, Oklahoma, caused large fish aggregations which resulted in increased winter angling yields. Grinstead (1965) found that light penetration and turbidity influenced white crappie distribution more than any other physicochemical factor in Buncombe Creek, Lake Texoma, Oklahoma.

Vertical fish distribution in relation to limnological factors in Keystone Reservoir was studied from September, 1965, to August, 1966. Designs for portable float units and net rollers were tested. The vertical latin-square net was compared statistically to a modified net design created for open-water sampling.

CHAPTER II

DESCRIPTION OF STUDY AREA

General Description of Keystone Reservoir

Keystone Dam crosses the Arkansas River at river mile 538.8 two miles downstream from the mouth of the Cimarron River and 15 miles west of Tulsa. Dam completion and closure in February, 1964, formed a 26,300 acre reservoir with a capacity of 663,000 acre-feet at normal power pool, 723 feet above sea level (Fig. 1).

Stream flow records of the Arkansas and Cimarron Rivers indicate that the reservoir impoundment level will be within two feet of normal power pool during three-fourths of the year (U.S.A.C.E., 1965).

Description of Stations

Fishes were collected at four stations in the Cimarron River arm of Keystone Reservoir (Fig. 1). Depth at each station was uniform throughout the study except at station 3. This station was moved 50 yards north of its original position in February, 1966, causing a change in depth from 10 to 14 meters. Depths of stations 1, 2, and 4 were 5, 10, and 18 meters respectively.

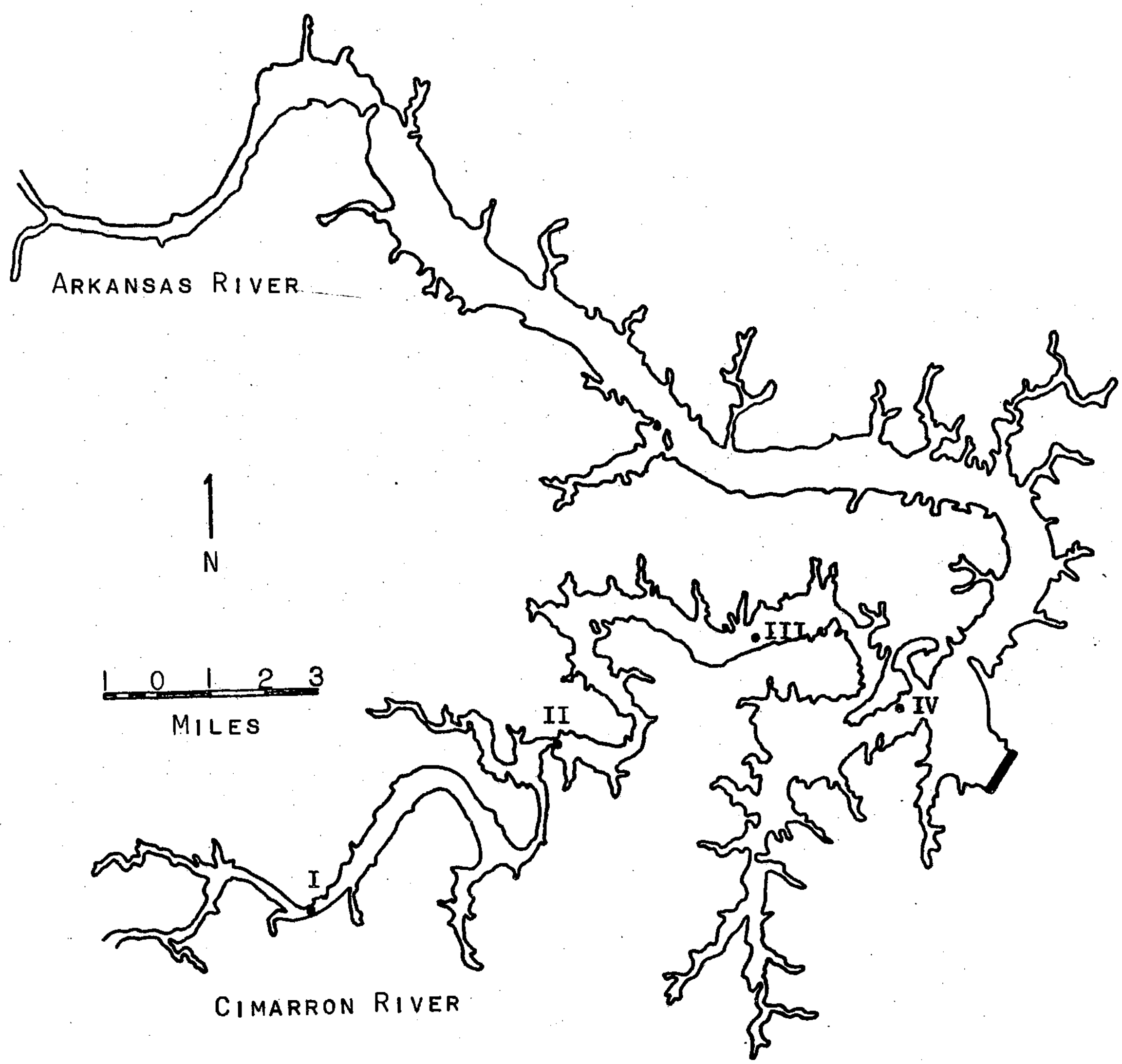

Figure 1. Keystone Reservoir, Oklahoma. Numbers indicate locations of sampling stations.

CHAPTER III

PROCEDURES AND MATERIALS

Float Designs

A rectangular wooden frame 24 feet long by 3 feet wide with a 2 foot stand at each end was used in the early part of the study. The stands acted as receptacles for a gill net roller (described later) and a traffic flasher light. Styrofoam-tipped boards were placed beneath the stands for added buoyancy and balance for the wooden frame. Other details of construction are given in Figure 2. Because of wave damage, these frames were replaced with a float unit design.

Each float unit frame was 3 by 3 feet square constructed of 4 by 4 inch redwood and 1 by 8 inch fir. A canvas-covered styrofoam block at each frame corner added buoyancy to the float unit. A centrally-located stand 2 feet high made of 4 by 4 inch redwood was divided into two parts. The bottom part was solidly attached to the frame and the top part was hinged to move forward and backward. A hole through the top portion of the stand held a net roller in position when the net was being raised or lowered. The jointed construction of the stand permitted the roller to stay on a relatively even plane regardless of wave action. A traffic flasher light was attached at the top of each stand. Other details of construction are given in Figure 3.

Two float unit frames were needed for each roller and net. Two nylon braided ropes held the float frames in position and gave

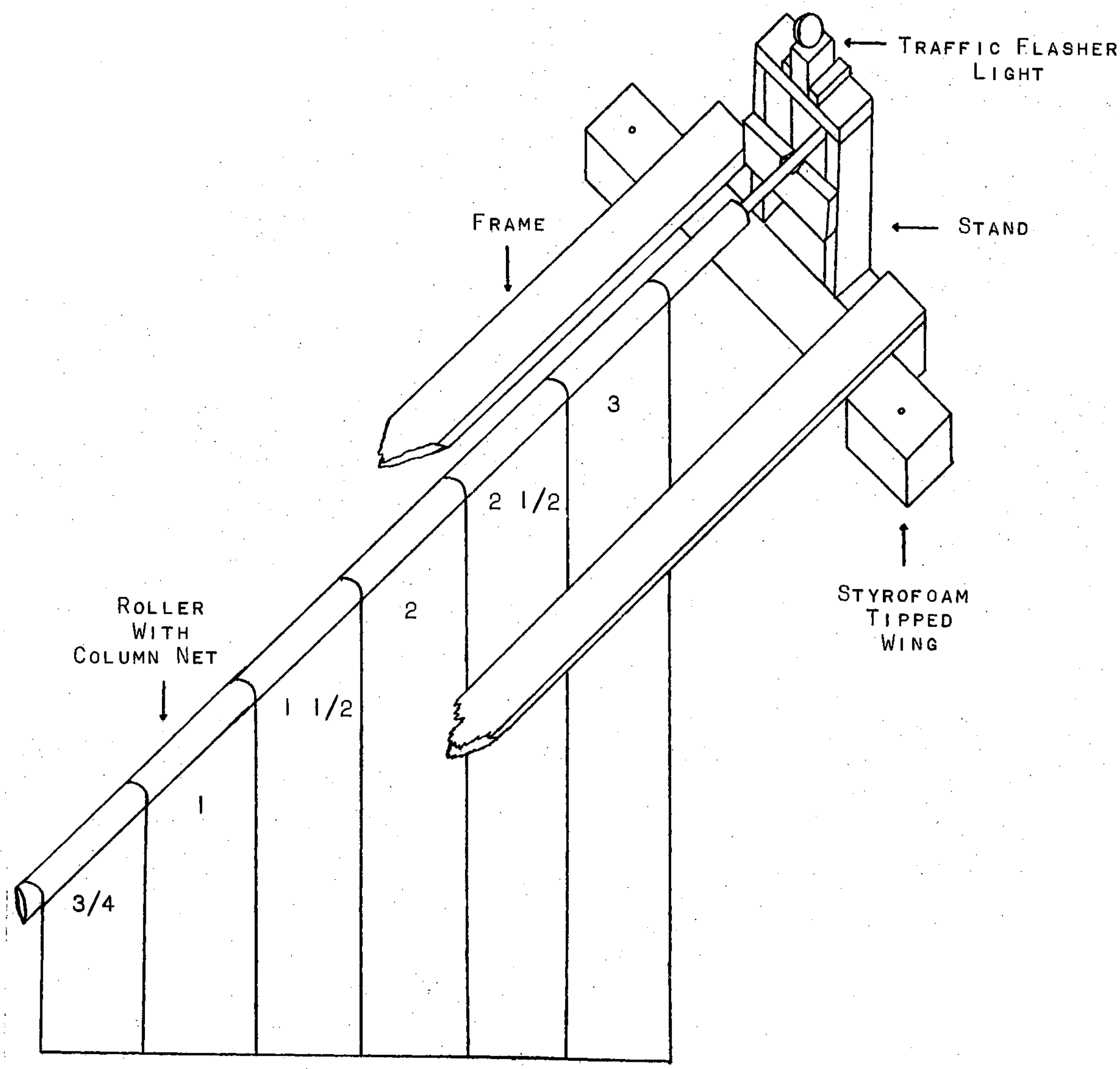

Figure 2. Wooden Frame Float Design With Column Gill Net in the Raise-Lower Position

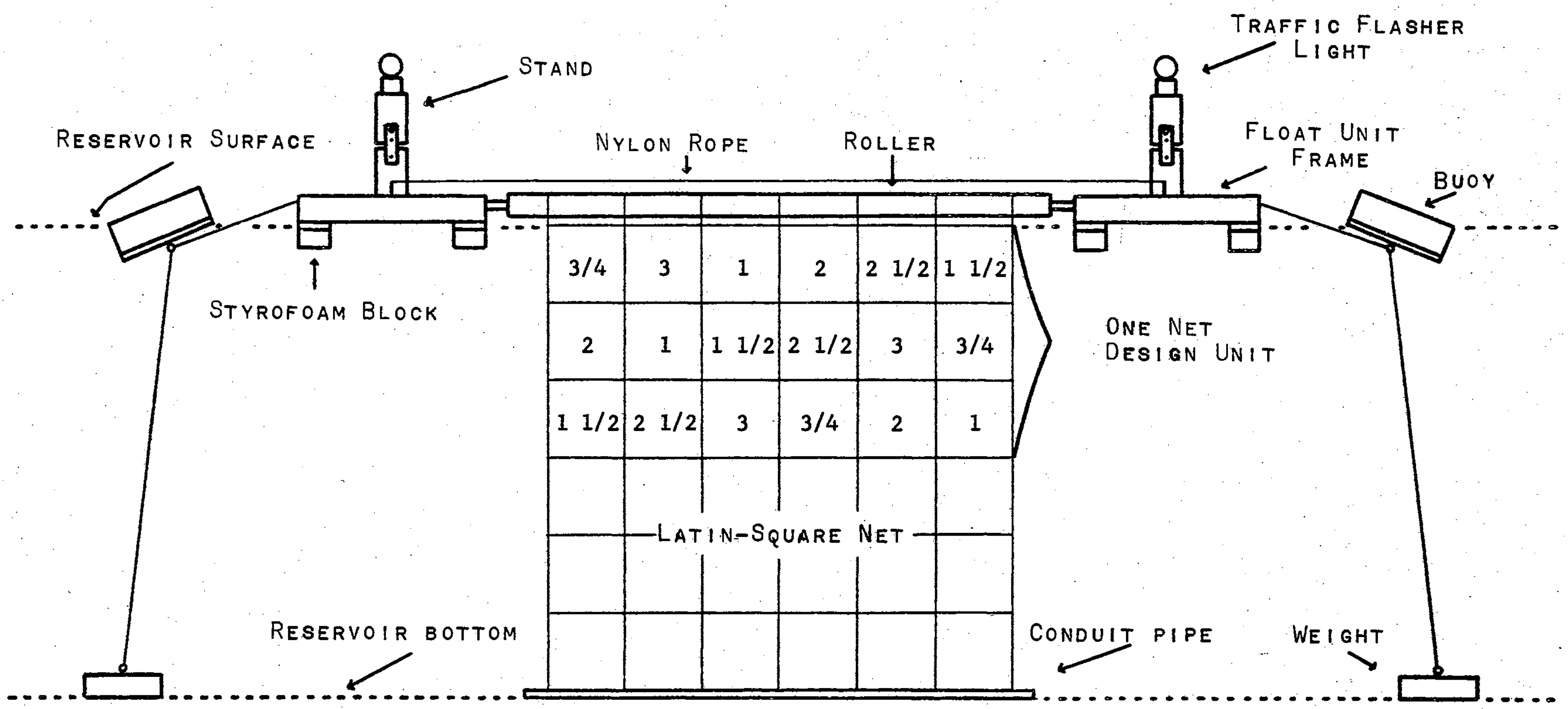

Figure 3. Float Unit Design With Latin-Square Gill Net in the Set Position

flexibility to the units so that wave damage was eliminated. Other nets can be fished in series with the first net by attaching one float unit to the system for each additional net.

Net Roller

A floatable net roller was made from a 20 foot long, 3 inch diameter plastic pipe. Wooden plugs with two feet of galvanized pipe projecting from their centers were sealed into the ends of the plastic pipe with waterproof glue.

The roller was tied to its float unit frame when in the set position. When in the raise-lower position, the roller was locked into the upper part of the float unit stand by pipe tees screwed on the roller pipes.

Vertical Latin-Square Net

Houser and Ghent (1964) incorporated the latin-square principle into an experimental gill net design. Rectangular designs were devised using 3 rows and 6 columns of cells 2 feet square. The cell arrangement criteria were such that each mesh occurred once in every row and once in the paired columns 1 and 2, 3 and 4, 5 and 6. Four net designs designated different mesh sizes by letters as follows:

(1)	A F B D E C	(3)	E A C B F D
	D B C E F A		C B F D A E
	C E F A D B		F D A E C B
(2)	E D A C F B	(4)	D A B E C F
	F B D E A C		B E F C D A
	C A F B D E		F C D A E B

The vertical latin-square net employed in the present study incorporated the designs of Houser and Ghent into a single net in a stack-like fashion (Fig. 3). This net was 6 meter-cells long and 21 meter-cells deep. A meter-cell is a meter square area containing webbing of one mesh size. The mesh sizes employed were: (A) 3/4-, (B) 1-, (C) 1 1/2-, (D) 2-, (E) 2 1/2-, and (F) 3-inch square measure. Each cell of #65 nylon webbing was hung on 1/2 basis with #36 nylon twine. The top line of the net was attached to the net roller. A 3/4 inch conduit pipe was attached to the bottom for weight.

Column Net

The vertical latin-square net was compared to an experimental column net designed for open-water sampling. Comparison of these nets involved catch rates, frequency distribution of species and size-class distribution.

The experimental net was composed of vertical columns of webbing of different mesh sizes linked together. Position of mesh sizes was determined by a table of random numbers (Fig. 2). Similar nets have been described by Horak and Tanner (1964), who used gill nets of a single mesh size extending from top to bottom of the reservoir.

Webbing, float, and leadline materials in the column net were identical to those used in the latin-square net. The net was 5 meters long and 21 meters deep. Meter depths of the net were color coded to mark the area of fish capture.

Biological and Physicochemical Analyses

Depth distribution of fishes was analyzed by seasons separated on the basis of temperature, as follows:

Fall - October, November, December,

Winter - January, February, March,

Spring - April, May, June,

Summer - June, July, August, September.

Physicochemical analyses of water were made at each station in conjunction with netting samples. Water temperature and conductivity were measured by an Industrial Instruments RB Solu Bridge. Depth was measured in meters. Dissolved oxygen was measured in mg/l from duplicate samples at each depth. Samples were fixed by the Alsterberg (Azide) modification of the Winkler method and titrated with .016 N sodium thiosulfate (A.P.H.A., 1960).

The number of fish caught at a given time is believed to be a function of time, location, etc. Hence, a statistical model is assumed to be:

$$Y_{ijk} = u + M_i + S_j + (MS)_{ij} + B_1X_{1_{ijk}} + B_2X_{2_{ijk}} + B_3X_{3_{ijk}} + B_4K + E_{ijk}$$

$$i = 1, 2, 3,$$

$$j = 1, 2, 3, 4,$$

$$k = 1, 2, \ldots, n_j,$$

where n_j is the depth in meters for station j. The terms of the model are defined as follows:

1. Y_{ijk} = the number of fish observed at the kth depth at the jth station in the ith month,

2. u = the true mean effect,

3. M_i = the ith month effect,

4. S_j = the jth station effect,

5. $(MS)_{ij}$ = the month-station interaction effect at the jth station to the ith month,

6. $X_{1_{ijk}}$ = the dissolved oxygen observed at the kth depth at the jth station in the ith month,

7. $X_{2_{ijk}}$ = the temperature observed at the kth depth at the jth station in the ith month,

8. $X_{3_{ijk}}$ = the specific conductance observed at the kth depth at the jth station in the ith month,

9. K = the depth observed,

10. E_{ijk} = a random variable which is assumed to have a normal distribution with mean zero and variance s^2.

In essence, this is a covariance model constructed to analyze the vertical distribution of gizzard shad, drum and all species combined in relation to physicochemical stratification during the summer season. The total response of combined species for the 12-month period of study was also measured. The physicochemical factors studied were temperature, oxygen, conductivity and depth. The Abbreviated Doolittle Method (Steel and Torrie, 1960) was used to determine the physicochemical factor which accounted for the most variability after adjustment for the other effects.

In order to make proper statistical inferences with the covariance model, certain assumptions (normality, equality of variances, etc.)

should be made. These assumptions were not strictly met, but the analysis was considered to be sufficiently informative.

Calculations were performed on an IBM 7040 data processing machine at the Oklahoma State University Computing Center.

CHAPTER IV

RESULTS AND DISCUSSION

Experimental Column Net Versus Vertical Latin-Square Net

In recent years, latin-square net designs have become popular for studying fish populations and distributions in lakes and reservoirs. Houser and Ghent (1964) were the first to study the net design in Oklahoma and recommended its use in small and large impoundments. However, they found that standard nets catch more fish and cost less to build than the latin-square net. In the present study a net design was developed to eliminate some disadvantages of the latin-square net.

Size class distribution among like meshes for the combined catch of all species is shown in Table I. The similarity of the catches by both nets is evident. At the individual mesh level the frequencies of occurrence are comparable. Agreement among totals of all meshes is good.

Catch rates of each species for the respective nets are listed in Table II. The Wilcoxon's signed rank test was applied to these data to detect differences between the two nets after the column net catch rate had been adjusted to compensate for its smaller size (Steel and Torrie, 1960). Differences were computed between the latin-square and column net catch rate and ranked. The sum of the negative rank was T = 30.5. This value, compared to a critical value of T (17) at the .05 probability level, indicated that the two nets were similar in catch rates.

TABLE I

LENGTH FREQUENCY OF CAPTURED SPECIES BY EACH MESH SIZE OF THE LATIN-SQUARE NET (L) AND THE COLUMN NET (C)

Total Length (Inch Classes)	Mesh 3/4 L	3/4 C	1 L	1 C	1 1/2 L	1 1/2 C	2 L	2 C	2 1/2 L	2 1/2 C	3 L	3 C	TOTAL L	TOTAL C
5.0 - 6.9	1296	956	20	15	3	6	1						1320	977
7.0 - 8.9	6	5	86	67	4	9	1	1					97	82
9.0 - 10.9	5	2	33	24	100	57	1	1	2			1	141	85
11.0 - 12.9	6	4	12	5	45	27	12	15	1		2		78	51
13.0 - 14.9	1		3	5	8	5	2	7					14	17
15.0 - 16.9	1		3		4	6	2	3		2			10	11
17.0 - 18.9	1						1				1		3	0
19.0 - 20.9			1			1	2	2			1		4	3
21.0 - 22.9							2				2	1	4	1
23.0 - 24.9														
25.0 - 26.9														
27.0 - 28.9														
29.0 - 30.9														1
TOTAL	1316	967	158	116	164	111	24	30	3	2	6	2	1671	1228

TABLE II

COMPARISON OF CATCH RATES OF EACH SPECIES CAUGHT IN THE LATIN-SQUARE AND THE COLUMN NET

Species	Latin-Square	Column Net	Adjusted Column Net (6/5 x Column Net)	Difference	Signed Rank
Gizzard shad	1300	922	1106.40	+193.60	+13
Black bullhead	87	103	123.60	- 36.60	-12
White bass	61	41	49.20	+ 11.80	+ 9
Carp	56	35	42.00	+ 14.00	+11
White crappie	51	31	37.20	+ 13.80	+10
Channel catfish	38	32	38.40	- 00.40	- 1
Goldeye	27	23	27.60	- 00.60	- 2 1/2
Smallmouth buffalo	16	9	10.80	+ 05.20	+ 7
Largemouth bass	12	14	16.80	- 04.80	- 6
Walleye	9	3	3.60	+ 05.40	+ 8
River carpsucker	7	9	10.80	- 03.80	- 5
Bluegill	4	4	4.80	- 00.80	- 4
Flathead	3	2	2.40	+ 00.60	+ 2 1/2
Total	1671	1228	1473.60		T = 30.5

The catch rate of each net was low when compared to conventional nets. To compensate for sample-size deficiencies the nets should have been set for a longer period, or a larger surface area should have been employed.

The column net has many advantages over the latin-square net. It presents a more continuous, unchanging surface as compared to the many contrasting changes in mesh density of the latin-square net which may cause greater visibility in the water. Time, effort, and cost of construction of the latin-square net are significantly greater than for the column net. For an equal amount of use, the experimental net suffers less damage than the latin-square net.

Fish Distribution

Eighteen species of fish were caught during the twelve month sampling period (Table III).

Gizzard shad. Analyses of variance for gizzard shad during the summer are given in Table IV. When oxygen or temperature were placed ahead of other measured factors in a covariance model, they accounted for the largest amount of variation. When oxygen approached or temperature was placed in the last position in the model, temperature accounted for a larger amount of variation than oxygen. On this basis, temperature appeared to affect the shad more than any other measured factor during the summer.

Gizzard shad ranked first in number in gill net catches. Size ranged from 4 to 14 inches, but most of the individuals were in the 5 to 7 inch range. The population tended to be concentrated near the surface of the reservoir in all seasons (Fig. 4). Shad were taken from all depths except in the lower strata when dissolved oxygen content was low.

Gizzard shad appeared to be more numerous at the upper stations during fall, but were found in larger numbers at station 4 during winter and spring. These fish were most numerous at the lower stations during summer.

TABLE III

FISH SPECIES AND NUMBERS OF INDIVIDUALS CAUGHT IN KEYSTONE RESERVOIR, 1965-66

Species	Total	
	Number	Percent
Gizzard shad (*Dorosoma cepedianum*)	1780	54.23
Drum (*Aplodinotus grunniens*)	565	17.21
Black bullhead (*Ictalurus melas*)	203	6.18
White bass (*Roccus chrysops*)	173	5.27
Carp (*Cyprinus carpio*)	128	3.90
Channel catfish (*Ictalurus punctatus*)	91	2.77
Shortnose gar (*Lepisosteus platostomus*)	81	2.46
White crappie (*Pomoxis annularis*)	76	2.31
Goldeye (*Hiodon alosoides*)	49	1.49
Longnose gar (*Lepisosteus osseus*)	32	.97
Largemouth bass (*Micropterus salmoides*)	28	.85
Smallmouth buffalo (*Ictiobus bubalus*)	27	.82
Walleye (*Stizostedion vitreum*)	24	.73
River carpsucker (*Carpiodes carpio*)	15	.45
Bluegill (*Lepomis macrochirus*)	4	.12
Flathead catfish (*Pylodictis olivaris*)	3	.09
Spotted gar (*Lepisosteus oculatus*)	2	.06
Green sunfish (*Lepomis cyanellus*)	1	.03
Total	3282	100.03

TABLE IV

A.O.V. FOR SHAD (SUMMER MONTHS)

	Source of Variation	Degrees of Freedom	Sum of Squares
1.	Total	144	41428.000
	R(u)	1	10643.361
	R(m/u)	2	1490.514
	R(s/adj)	3	1764.729
	R(m x s/adj)	6	3145.167
	Oxygen	1	9760.090
	Conductivity	1	1607.721
	Depth	1	1248.073
	Temperature	1	2019.243
	Remainder	128	9749.103
2.	Total	144	41428.000
	R(u)	1	10643.361
	R(m/u)	2	1490.514
	R(s/adj)	3	1764.729
	R(m x s/adj)	6	3145.000
	Temperature	1	13652.215
	Oxygen	1	270.267
	Depth	1	61.277
	Conductivity	1	651.369
	Remainder	128	9749.103
3.	Total	144	41428.000
	R(u)	1	10643.361
	R(m/u)	2	1490.514
	R(s/adj)	3	1764.729
	R(m x s/adj)	6	3145.167
	Temperature	1	13652.215
	Conductivity	1	920.584
	Oxygen	1	54.999
	Depth	1	7.330
	Remainder	128	4624.579
4.	Total	144	41428.000
	R(u)	1	10643.361
	Temperature	1	7121.416
	Oxygen	1	1366.657
	Conductivity	1	2085.036
	Depth	1	962.936
	R(m/adj)	2	986.474
	R(s/adj)	3	4782.393
	R(s x m/adj)	6	3730.624
	Remainder	128	9749.103

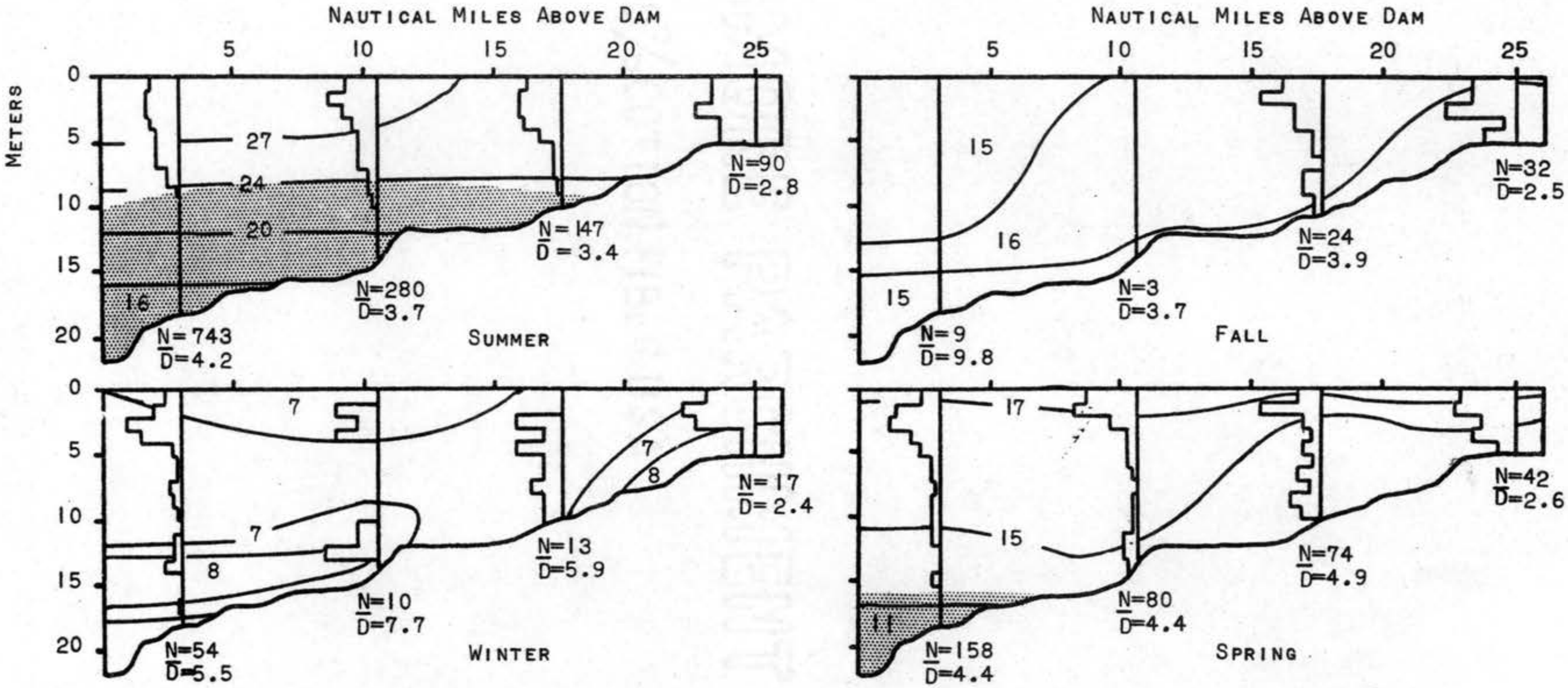

Figure 4. Vertical Distribution of Gizzard Shad in all Seasons. Station locations are indicated by Roman numerals. N = number of fish. D = mean depth of capture. Contours = temperature C. Shaded areas = oxygen 2 mg/l or less.

Small numbers of gizzard shad caught during the fall and winter may have been part of the 1964 year-class that hatched in the river before dam closure. Increase in captures during spring and summer is believed to have been caused by recruitment of a larger 1965 reservoir year-class.

<u>White bass</u>. Size for these fish ranged from 6 to 14 inches. Vertical distribution for white bass was similar to that of gizzard shad (Fig. 5). It is believed that white bass were feeding on gizzard shad.

White bass were more numerous at stations 1 and 2 during fall and winter; they had almost disappeared from the sampling areas in spring. Absence of these fish from the sample areas in spring was attributed to onset of spawning migrations up the Cimarron River or into the shallow, rocky shoal areas of the reservoir. They returned to the lower reaches of the reservoir during summer where large concentrations of gizzard shad occurred.

<u>Drum</u>. Drum, white crappie, black bullhead, carp, gars, and channel catfish data were too few to merit discussion except for the summer season. The analyses of variance for drum in the summer are given in Table V. Measured factors were not significant at the 0.05 probability level, indicating that depth distribution of drum may not have been influenced by any of the measured factors.

Size of drum ranged from 3 to 10 inches. These fish were found in water ranging from 19 to 27 C (Fig. 6). At stations 1, 2 and 3 drum were concentrated in the middle depths, while at station 4 they occurred near the surface. A few drum were caught in water with less than 2 mg/l dissolved oxygen.

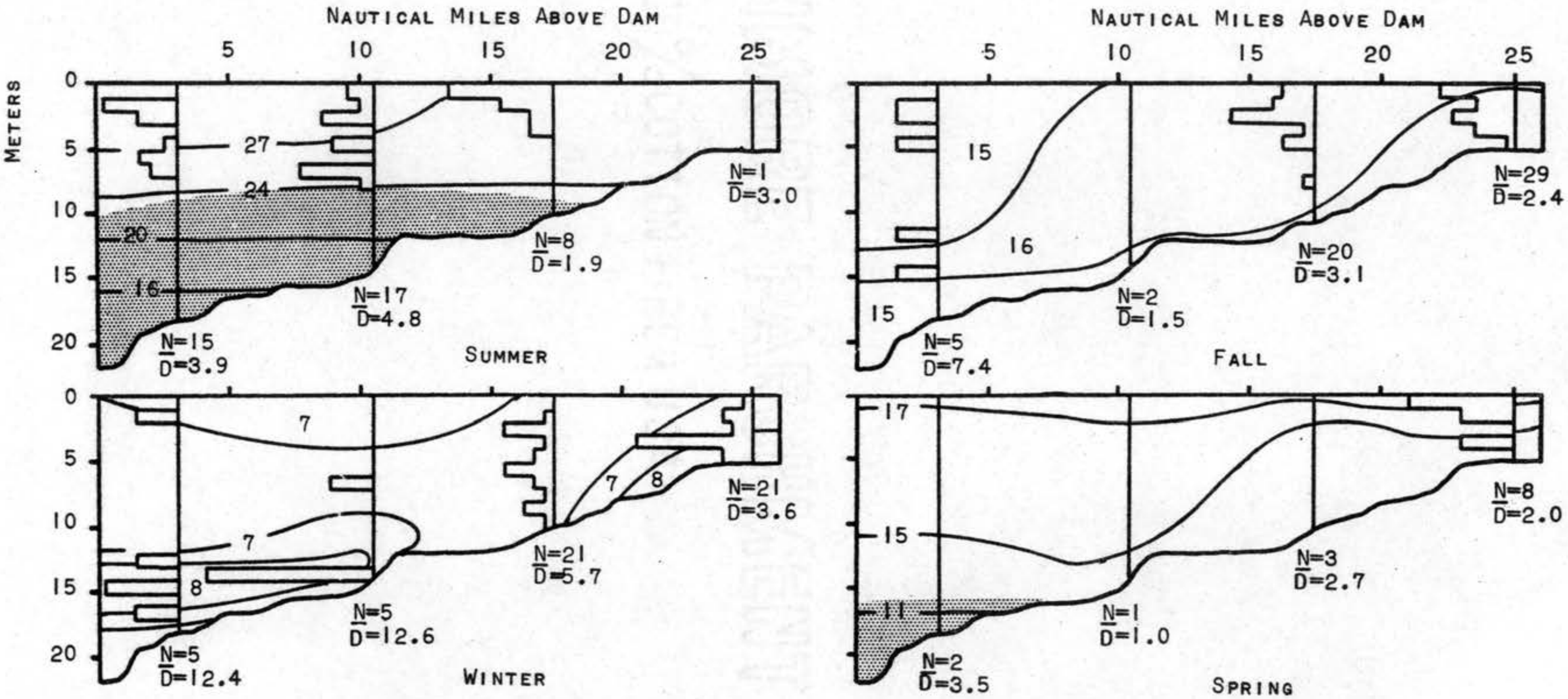

Figure 5. Vertical Distribution of White Bass in all Seasons. See Figure 6 for legend.

TABLE V

A.O.V. FOR DRUM (SUMMER MONTHS)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
1. Total	144	8244.000		
R(u)	1	1122.250		
R(m/u)	2	60.667		
R(s/adj)	3	1307.697		
R(m x s/adj)	6	940.401		
Oxygen	1	4.147	4.147	0.114
Conductivity	1	64.572	64.572	1.787
Depth	1	0.006	0.006	0.000
Temperature	1	119.682	119.682	3.312
Remainder	128	4624.579	36.129	
2. Total	144	8244.000		
R(u)	1	1122.250		
R(m/u)	2	60.667		
R(s/adj)	3	1307.697		
R(m x s/adj)	6	940.401		
Temperature	1	34.466	34.466	0.953
Oxygen	1	96.257	96.257	2.664
Depth	1	56.105	56.105	1.552
Conductivity	1	1.580	1.580	0.043
Remainder	128	4624.579	36.129	
3. Total	144	8244.000		
R(u)	1	1122.250		
R(m/u)	2	60.667		
R(s/adj)	3	1307.697		
R(m x s/adj)	6	940.401		
Temperature	1	34.466	34.466	0.953
Conductivity	1	0.227	0.227	0.006
Oxygen	1	103.275	103.275	2.858
Depth	1	50.440	50.440	1.396
Remainder	128	4624.579	36.129	
4. Total	144	8244.000		
R(u)	1	1122.250		
Temperature	1	479.249		
Oxygen	1	136.858		
Conductivity	1	0.909		
Depth	1	31.947		
R(m/adj)	2	19.129		
R(s/adj)	3	1048.912		
R(s x m/adj)	6	780.167	130.027	3.598
Remainder	128	4624.579	36.129	

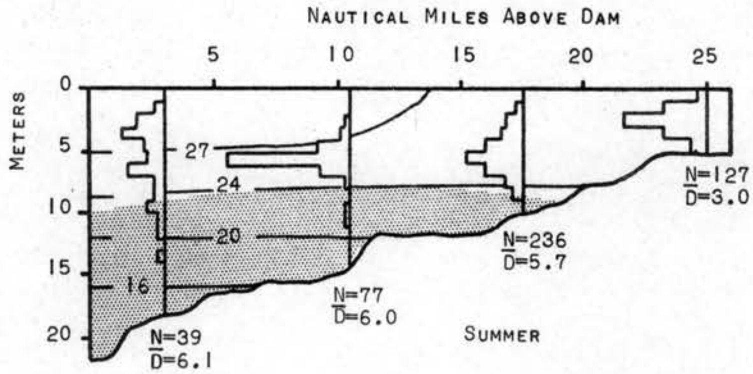

Figure 6. Vertical Distribution of Drum During Summer. See Figure 6, 4 for legend.

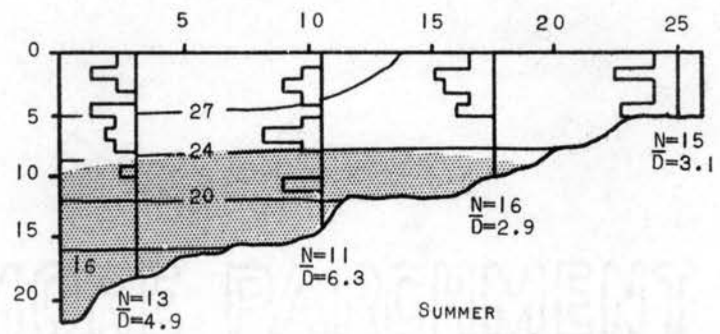

Figure 7. Vertical Distribution of White Crappie During Summer. See Figure 6 for legend.

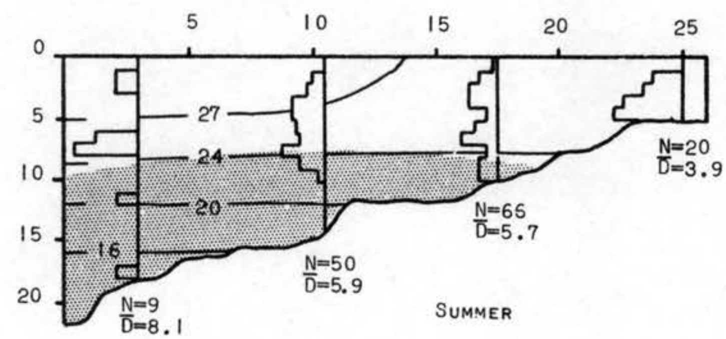

Figure 8. Vertical Distribution of Black Bullhead During Summer. See Figure 6 for legend.

During the summer, most drum were captured in the upper reaches of the reservoir. Because drum movement increased at all stations when heavy rains brought an influx of fresh water into the reservoir, it is believed that differences in catches between reservoir areas may have been due to a greater influence of the Cimarron River on the upper stations. Anoxic condition in the hypolimnion at the lower stations is another possible explanation for area differences in catches. Drum may have been forced to move into shoreline or upstream areas for better food.

White crappie. These fish were small, ranging from 4 to 7 inches. White crappie were caught from the surface to 9 meters of depth at all stations (Fig. 7). The small catch of white crappie was attributed to their being partial to sheltered areas, whereas sampling was restricted to cleared, open areas.

Black bullhead. Size of these fish ranged from 5 to 7 inches, although a few reached 12 inches. Most bullheads were found in water above 24 C (Fig. 8). They appeared to be more tolerant of low dissolved oxygen content than most fishes. Black bullheads seemed to prefer the middle portions of the reservoir.

Carp. Size of these fish ranged from 5 to 21 inches. Carp were found in water ranging from 16 to 28 C (Fig. 9). Many were in water with less than 2 mg/l dissolved oxygen. Fish occurred at the bottom of station 4 during September when anoxic conditions were absent.

Gars. Longnose, shortnose, and spotted gars were combined to facilitate discussion of their vertical distributions (Fig. 10). Size of gars ranged in length from 16 to 31 inches. These fish were caught

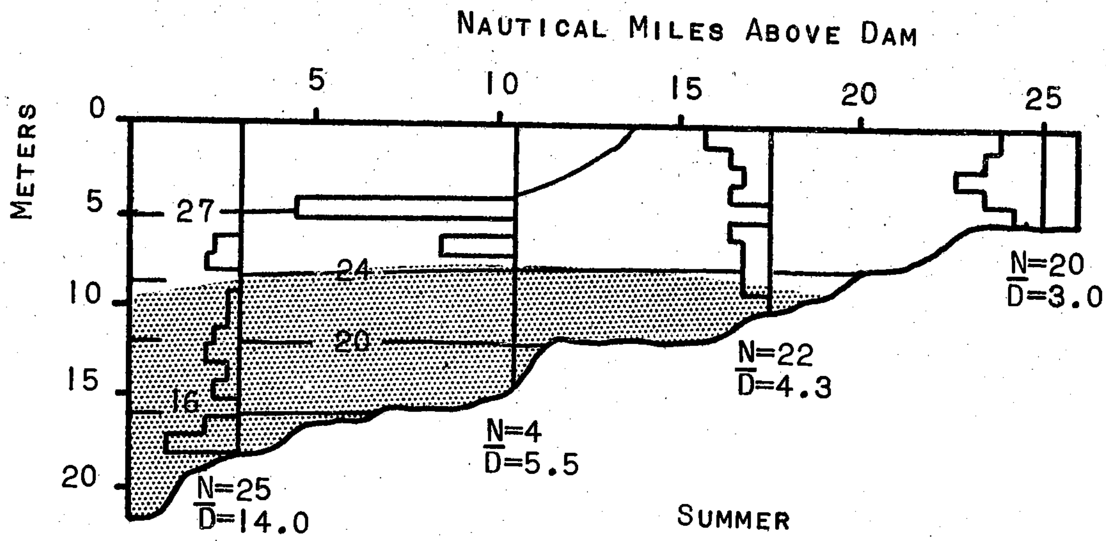

Figure 9. Vertical Distribution of Carp During Summer. See Figure 6 for legend.

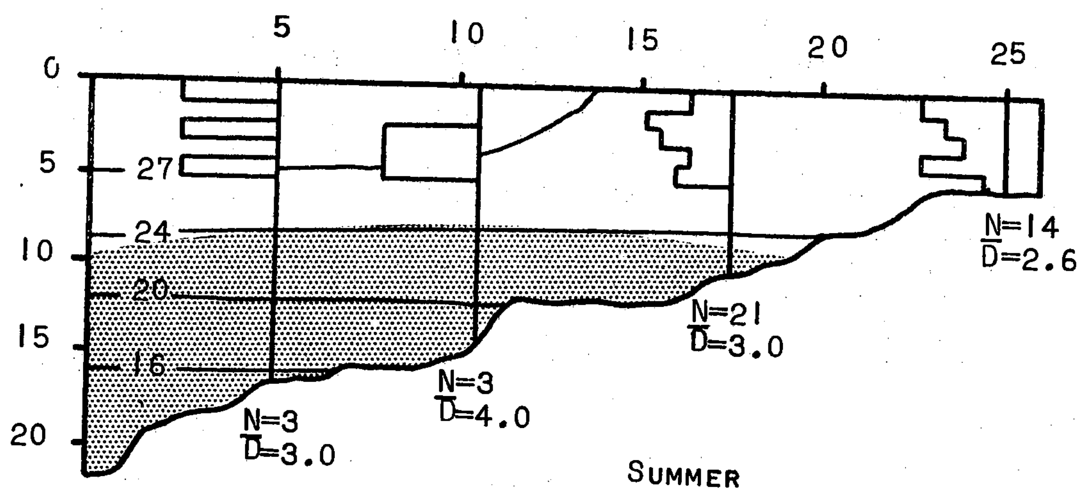

Figure 10. Vertical Distribution of Gars During Summer. See Figure 6 for legend.

near the surface where the warmest water occurred. Most gars were captured in the upper reaches of the reservoir.

Channel catfish. Sufficient data were not available for distribution analyses at stations 2, 3 and 4. At station 1, channel catfish were concentrated in the lower depths during the fall and winter, and were distributed at all depths in the spring (Fig. 11). A split distribution occurred during the summer.

Other species. Goldeye were captured near the surface at all stations during all seasons. Largemouth bass were taken during fall, spring, and summer near the surface. Smallmouth buffalo preferred the middle part of the water mass during the fall and spring, and the lower and surface parts during winter and summer, respectively. Walleye were captured within 4 meters of the surface during the summer. A wide vertical distribution for river carpsuckers existed during all seasons. All sunfishes were caught during fall and spring within 3 meters of the surface. Flatheads were taken during late winter and spring from near the bottom.

Combined species. The analyses for combined species in the summer are given in Table VI. The results were similar to those obtained for the gizzard shad. Temperature probably affected combined species more than any other measured factor. An analysis computed for a 12 month period (Table VII) also showed that temperature had a much greater effect than the other physicochemical factors.

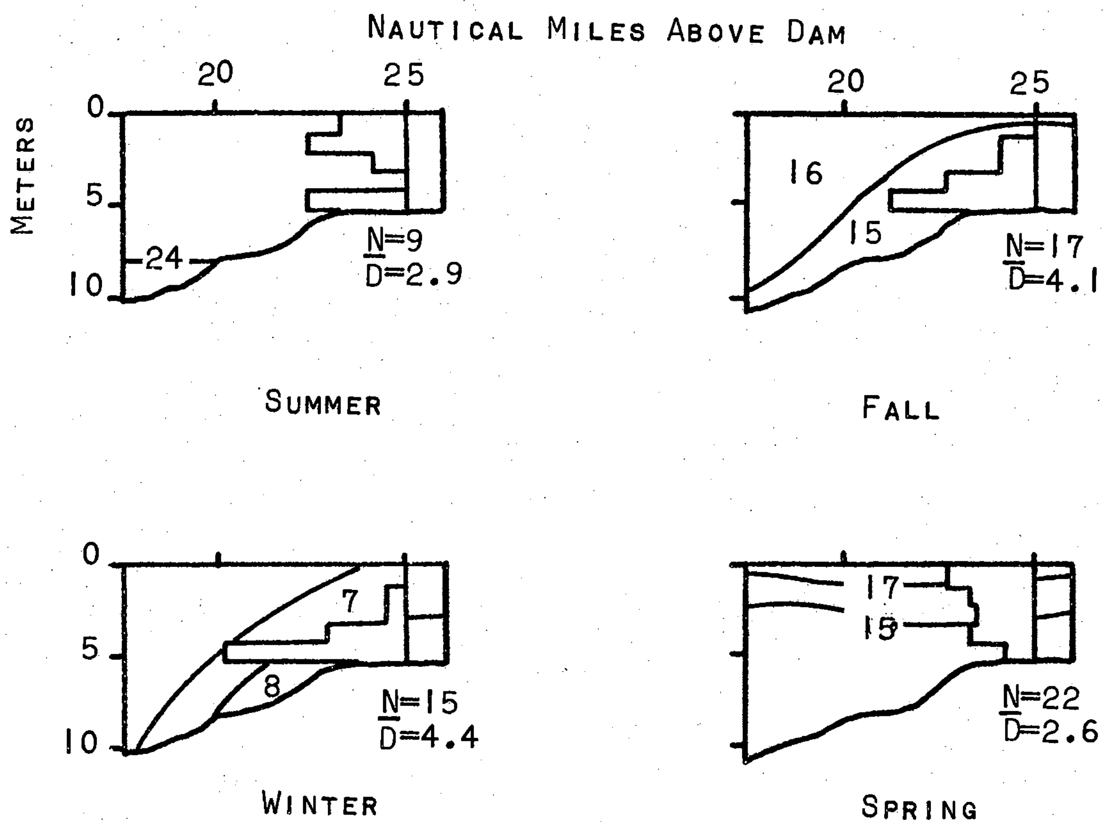

Figure 11. Vertical Distribution of Channel Catfish in all Seasons. See Figure 6 for legend.

TABLE VI

A.O.V. FOR COMBINED SPECIES (SUMMER MONTHS)

	Source of Variation	Degrees of Freedom	Sum of Squares
1.	Total	144	66547.000
	R(u)	1	26271.007
	R(m/u)	2	1902.056
	R(s/adj)	3	755.415
	R(m x s/adj)	6	4300.477
	Oxygen	1	10993.869
	Conductivity	1	2882.562
	Depth	1	1789.068
	Temperature	1	3284.243
	Remainder	128	14368.305
2.	Total	144	66547.000
	R(u)	1	26271.007
	R(m/u)	2	1902.056
	R(s/adj)	3	755.415
	R(m x s/adj)	6	4300.477
	Temperature	1	17921.664
	Oxygen	1	37.982
	Depth	1	131.427
	Conductivity	1	858.670
	Remainder	128	14368.305
3.	Total	144	66547.000
	R(u)	1	26271.007
	R(m/u)	2	1902.056
	R(s/adj)	3	755.415
	R(m x s/adj)	6	4300.477
	Temperature	1	17921.664
	Conductivity	1	983.554
	Oxygen	1	13.861
	Depth	1	30.664
	Remainder	128	14368.305
4.	Total	144	66547.000
	R(u)	1	26271.007
	Temperature	1	14401.426
	Oxygen	1	829.089
	Conductivity	1	2998.289
	Depth	1	251.142
	R(m/adj)	2	708.364
	R(s/adj)	3	2213.836
	R(s x m/adj)	6	4505.542
	Remainder	128	14368.306

TABLE VII

A.O.V. FOR COMBINED SPECIES (TWELVE MONTHS)

Source of Variation	Degrees of Freedom	Sum of Squares
Total	557	79163.000
R(u)	1	19232.548
R(m/adj)	11	13983.645
R(s/adj)	3	1327.834
R(m x s/adj)	33	5474.089
Temperature	1	18448.108
Conductivity	1	4.245
Oxygen	1	389.355
Depth	1	42.472
Remainder	505	19592.598

Physicochemical Observations

Eley's (1967) description of the limnological features of Keystone Reservoir includes the fish distribution study period. A summary of the mean physicochemical data are given in Appendix A.

Effects of a Flood on Fish Distribution in Keystone Reservoir

Flood waters entered the Cimarron arm of Keystone Reservoir in September, 1965. The Cimarron River discharge increased from 452 cfs on 20 September, to 41,529 cfs on 22 September. An oil slick covered most of the water surface. Vertical fish distribution and physicochemical parameters were determined before and after flood waters had reached a point 9.6 nautical miles upstream from the confluence of the Arkansas and Cimarron arms of the reservoir. A vertical latin-square net was set from the surface to the bottom (0-11 meters) for two 24-hour periods. Temperature, turbidity, conductivity and dissolved oxygen were determined at each meter of depth. Approximately uniform physicochemical conditions prevailed at the sampling site before flooding (Fig. 12). Temperature was constant, turbidity and conductivity increased slightly and oxygen decreased with depth.

Flood water entering the reservoir was cooler and less conductive. This water also carried a heavy load of suspended solids and organic matter and sank below the lighter reservoir water at the beginning of the flood. As the flood progressed these waters mixed, dilution first occurring in the bottom layers and working upward toward the surface. During the period of measurement complete mixing occurred up to a point four meters below the surface as shown by temperature, turbidity and conductivity measurements. During the 48-hour period temperature decreased from 25.2 to 20.8 C, turbidity increased from 40 to 320 turbidity units, specific conductance decreased from 2750 to 1450 micromhos, and dissolved oxygen decreased from 5.6 to 1.4 mg/liter. The severe reduction in dissolved oxygen was attributed to high oxygen demand of dissolved organic substances.

Fishes responded to the physicochemical changes by moving closer to the surface, and distressed fishes were observed swimming at the surface of the water. Mean depth of capture of all species changed from 5.70 to 3.28 meters (Fig. 13). A t-test applied to the differences between paired numbers of fishes caught at meter intervals gave a t = 2.45 with 112 degrees of freedom, which indicated significant differences between the two depth averages (p 0.05).

Oxygen and turbidity were probably the critical factors causing a change in the mean depth of fish distribution. Whitmore, Warren, and Doudoroff (1960) found that centrarchids have almost instantaneous

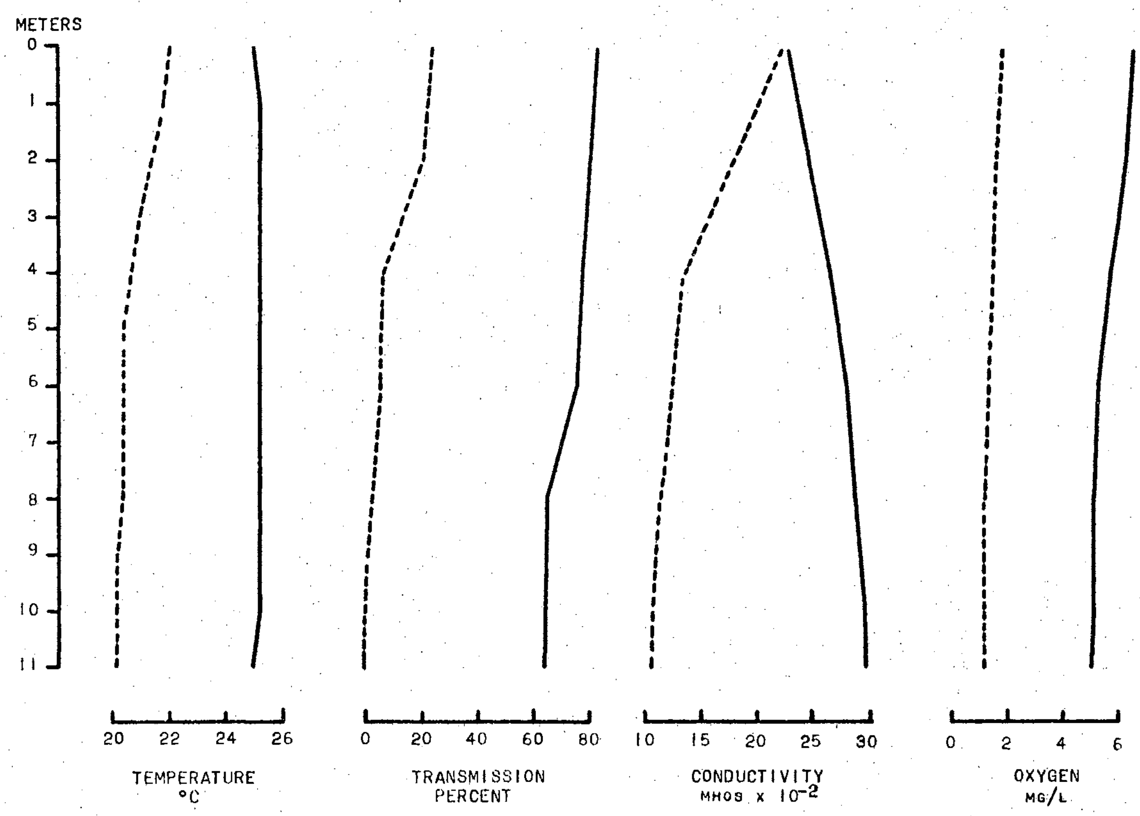

Figure 12. Change in Temperature, Turbidity, Conductivity and Oxygen Before and During Flooding at Station 3. Before flooding = (———), During flooding = (----).

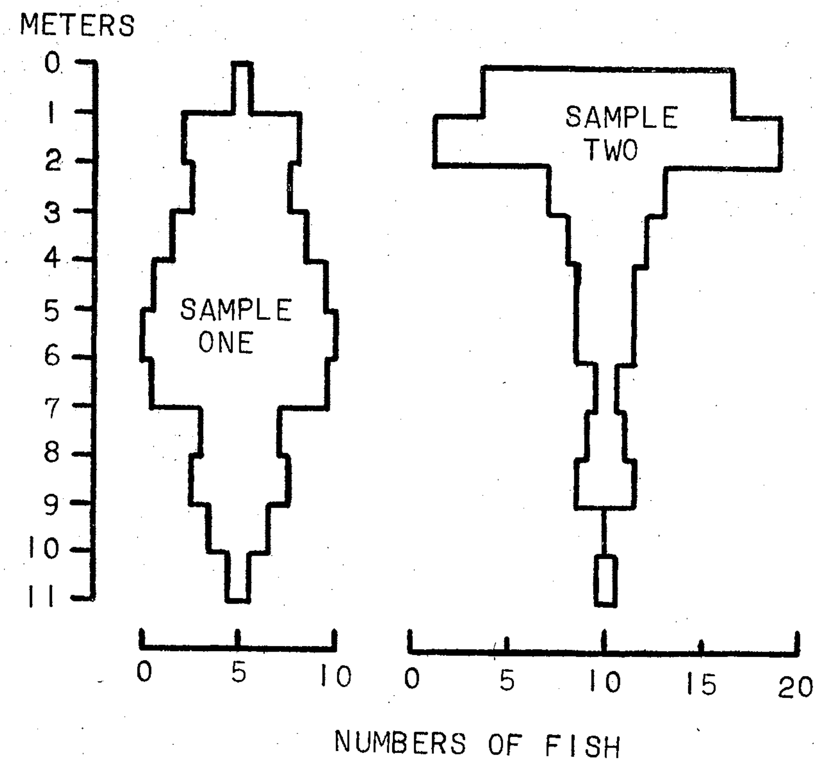

Figure 13. Change in Vertical Distribution of Fishes Before (Sample One) and After Flooding (Sample Two) at Station 3. Bar width for each depth interval represents percentage of total catch for a 24-hour sampling period.

responses to changes in oxygen concentrations. Other authors also have noted fish reaction to oxygen deficiency by moving away and by developing respiratory distress (Shelford and Allee, 1913; Jones, 1952). Wallen (1951) observed that the first reaction of fishes to turbidity is movement to the surface of the water, rapid swimming and gulping air and surface water.

Drum reacted to physicochemical changes more than any other fish by decreasing their mean depth 3.49 meters (Table VIII). White bass showed a distinct reaction to these changes by decreasing their mean depth 2.90 meters. All other species decreased their mean depths, except carp which increased 2.11 meters. Carp were unaffected by the increase in turbidity below four meters where 320 ppm occurred.

TABLE VIII

NUMBERS OF FISHES AND THEIR MEAN DEPTHS OF CAPTURE BEFORE AND DURING FLOODING

Species	Sample One		Sample Two	
	Nos.	$\bar{D}$ Depth	Nos.	$\bar{D}$ Depth
Drum	22	5.73	34	2.24
Carp	11	4.09	5	6.20
Gizzard shad	8	7.88	5	7.00
Black bullhead	7	6.29	3	6.00
White bass	5	4.40	4	1.50
Channel catfish	4	5.73	1	4.00
Walleye	2	6.50	1	6.00
White crappie	1	5.00	1	1.00

CHAPTER V

SUMMARY

1. Vertical fish distribution in relation to limnological factors in Keystone Reservoir was studied from September, 1965, to August, 1966. A design for a portable float unit was tested. The vertical latin-square net was compared to an experimental column net.

2. Temperature appeared to affect vertical distribution of shad and combined species more than any other measured factor. Depth distribution of drum may not have been influenced by any of the measured factors.

3. Oxygen content lower than 2 mg/l may have limited fish distribution. As oxygen depletion increased during spring and summer, fishes moved to aerated water above the chemocline. Only drum, white crappie, black bullhead and carp were caught in water with 2 mg/l or less dissolved oxygen.

4. Fishes responded to physicochemical changes caused by a flood by moving closer to the surface. Oxygen and turbidity were probably the critical factors causing a decrease in the mean depth where fishes were taken.

5. Gizzard shad and white bass tended to be concentrated near the surface of the reservoir in all seasons. Horizontal distribution of these two fishes was similar, except during spring when white bass had almost disappeared from the sampling areas. Absence of white bass from

the sample areas in spring was attributed to their spawning behavior. Drum concentrations were found near mid-depth during the summer, with greater numbers in the upper reaches of the reservoir. White crappie were distributed generally throughout the reservoir from 0 to 9 meters depth during the summer. Black bullheads were distributed in the middle reaches of the reservoir and were concentrated in water above 24 C during the summer. Carp had a wide horizontal and vertical distribution during the summer. Gars were more numerous in the upper reaches of the reservoir near the surface during the summer. Channel catfish were concentrated in the upper reaches of the reservoir in the lower depths during the fall and winter. They were distributed at all depths in the spring, and had a split distribution during the summer.

6. A portable float unit was constructed of two unit frames held together by ropes. This arrangement gave flexibility to the unit frames, thereby preventing wave damage. The jointed construction of the stand on each unit frame permitted a net roller to stay on a relatively even plane regardless of wave action.

7. The latin-square net and column net were statistically similar in catch rates but the latter had some advantages. It presented a more continuous, unchanging surface as compared to the many contrasting changes in mesh density of the latin-square net which could have caused greater visibility in the water. Time, effort, and cost of construction of the latin-square net was significantly greater than that of the column net. For an equal amount of use, the experimental net suffered less damage than the latin-square net.

LITERATURE CITED

American Public Health Association. 1960. Standard methods for the examination of water and waste-water. A.P.H.A. 11th Ed. 626 p.

Bryan, Paul and Henry H. Howell. 1946. Depth distribution of fish in lower Wheeler Reservoir, Alabama. Rept. Reelfoot Lake Biol. Sta., 10: 4-9. (Reprinted in J. Tenn. Acad. Sci., 21(1): 4-9.)

Cady, Earl R. 1945. Fish distribution, Norris Reservoir, Tennessee, 1943. I. Depth distribution of fish in Norris Reservoir. Rept. Reelfoot Lake Biol. Sta., 9: 103-114. (Reprinted in J. Tenn. Acad. Sci., 20(1): 103-114.)

Dendy, Jack S. 1945. Fish distribution, Norris Reservoir, Tennessee, 1943. II. Depth distribution of fish in relation to environmental factors, Norris Reservoir. Rept. Reelfoot Lake Biol. Sta., 9: 114-135. (Reprinted in J. Tenn. Acad. Sci., 20(1): 114-135.)

Eley, Rex L. 1967. Physicochemical stratification of Keystone Reservoir, Oklahoma. M.S. Thesis, Oklahoma State University, 30 p.

Grinstead, Bobby G. 1965. The vertical distribution of the white crappie, Pomoxis annularis, in Buncombe Creek arm of Lake Texoma. M.S. Thesis, Oklahoma University, 90 p.

Hancock, H. M. 1954. Investigations and experimentation relative to winter aggregations of fishes in Canton Reservoir, Oklahoma. Res. Found. Pub. No. 58, Okla. Agr. and Mech. Coll., Stillwater, Oklahoma, 104 p.

Haslbauer, Otto F. 1945. Fish distribution, Norris Reservoir, Tennessee, 1943. III. Relation of the bottom to fish distribution, Norris Reservoir. Rept. Reelfoot Lake Biol. Sta., 9: 135-138. (Reprinted in J. Tenn. Acad. Sci., 20(1): 135-138.)

Houser, Alfred and Arthur W. Ghent. 1964. An experimental gill net based on the principle of the latin square. Trans. Amer. Fish. Soc., 93(3): 233-242.

Horak, Donald L. and Howard A. Tanner. 1964. The use of vertical gill nets in studying fish depth distribution, Horsetooth Reservoir, Colorado. Trans. Am. Fish. Soc., 93(2): 137-145.

Jones, J. R. E. 1952. The reactions of fish to water of low oxygen concentration. J. Exp. Biol., 29: 403-415.

Loomis, Robert H. and William H. Irwin. 1954. A report of a study designed to determine the depth distribution of fishes in relation to vertical temperature. Res. Found. Pub. No. 56, Okla. Agr. and Mech. Coll., Stillwater, Oklahoma, 20 p.

Shelford, V. E. and W. C. Allee. 1913. The reactions of fishes to gradients of dissolved atmospheric gases. J. Exp. Zool., 14(2): 207-266.

Steel, Robert G. D. and James H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. 481 p.

U. S. Army Corps of Engineers. 1965. Unpublished discharge records for the Cimarron River and Keystone Reservoir. District Office, U. S. Army Corps of Engineers, Tulsa, Oklahoma.

Wallen, I. E. 1951. The direct effect of turbidity on fishes. Okla. Agr. and Mech. Coll. Biol. Ser. Bull., 48(2): 27 p.

Whitmore, Cecil M., Charles E. Warren, and Peter Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Amer. Fish. Soc., 89(1): 17-26.

Wiebe, A. H. 1941. Density currents in impounded waters - their significance from the standpoint of fisheries management. Trans. N. Amer. Wildl. Conf. 6: 256-264.

APPENDIX A

MEAN PHYSICOCHEMICAL DATA AT EACH METER LEVEL OF THE FOUR STATIONS FOR WINTER, SPRING, SUMMER, AND FALL
Data obtained by Eley (1965-66)

		Winter			Spring			Summer			Fall		
		Temp.	O_2	Cond.	Temp.	O_2	Cond.	Temp.	O_2	Cond.	Temp.	O_2	Cond.
	Depth	F	ppm	u mhos	F	ppm	u mhos	F	ppm	u mhos	F	ppm	u mhos
	0	7.2	13.1	2766.7	16.1	10.5	4825.0	27.9	5.5	2700	16.2	9.6	2016.7
	1	7.1	13.1	2766.7	15.5	10.5	4825.0	27.5	5.3	2780	15.7	9.6	2016.7
Sta. 1	2	7.2	12.9	2966.7	15.2	10.5	4950.0	27.0	4.9	2848	15.3	9.3	2080.0
	3	7.6	11.6	5300.0	15.1	10.4	6000.0	26.8	4.9	3507	14.8	8.9	3683.3
	4	8.0	10.8	9083.3	13.9	10.3	9500.0	26.6	4.9	3984	16.6	8.5	5316.7
	5	8.0	10.5	9333.3	13.9	10.0	9550.0	25.3	2.9	5604	15.4	8.3	5833.3
	0	6.4	11.7	2366.7	17.0	10.4	3500.0	27.9	6.6	2161	16.4	8.1	1290.0
	1	6.4	11.5	2366.7	14.9	10.3	3500.0	27.1	6.2	2296	16.1	8.1	1290.0
	2	6.4	11.4	2366.7	14.8	10.3	3500.0	27.0	6.2	2296	16.0	8.0	1300.0
	3	6.3	11.5	2366.7	14.2	9.8	3500.0	26.5	5.3	2321	15.8	7.9	1330.0
	4	6.3	11.4	2366.7	13.9	9.3	3500.0	26.3	4.7	2341	15.5	7.7	1330.0
Sta. 2	5	6.2	11.5	2366.7	13.9	9.1	3500.0	26.0	4.3	2366	15.5	7.7	1330.0
	6	6.0	11.6	2400.0	13.9	8.8	2650.0	25.7	3.6	2479	15.4	7.7	1360.0
	7	5.9	11.5	2416.7	13.9	8.4	3975.0	25.3	3.0	2537	15.6	7.7	1433.3
	8	6.1	11.1	4166.7	14.2	8.1	6050.0	24.9	1.7	2717	15.6	7.7	1530.0
	9	5.9	11.3	5000.0	14.8	6.1	7750.0	24.3	1.4	2862	16.2	7.7	4333.3
	10	5.7	11.5	9816.7	14.8	5.6	7750.0	23.4	1.0	3368	16.2	7.7	6166.7
	0	7.3	12.2	2383.3	16.9	10.1	3125.0	28.0	7.4	2333	16.0	7.8	1346.7
	1	7.2	12.2	2383.3	16.8	10.0	3125.0	28.0	7.3	2338	15.9	7.8	1346.7
	2	6.8	12.1	2383.3	16.7	10.0	3125.0	27.7	7.1	2380	15.9	7.8	1346.7
	3	6.6	11.7	2383.3	16.4	9.4	3125.0	27.5	6.2	2380	15.9	7.8	1346.7
	4	6.5	11.2	2383.3	16.3	9.4	3125.0	27.3	5.3	2448	15.9	7.6	1346.7
	5	6.4	11.1	2391.7	16.1	9.3	3175.0	26.9	3.6	2448	15.9	7.6	1346.7
	6	6.3	11.1	2400.0	16.0	8.8	3275.0	26.3	3.1	2475	15.9	7.6	1346.7
Sta. 3	7	6.3	11.0	2400.0	15.8	8.2	3425.0	25.5	2.0	2487	15.9	7.6	1346.7
	8	6.3	11.0	2400.0	15.5	7.7	3425.0	24.9	1.7	2533	15.9	7.6	1346.7
	9	6.4	10.8	2433.3	15.5	7.6	3425.0	24.1	1.3	2648	15.9	7.6	1380.0
	10	6.5	10.7	2616.7	15.1	7.4	3425.0	23.2	1.3	2825	15.9	7.6	1463.3
	11	6.6	10.6	2950.0	15.0	7.1	3425.0	21.8	1.2	3103			
	12	6.6	10.4	5800.0	15.0	6.9	3575.0	19.6	0.0	3666			
	13	7.7	10.0	9033.3	15.3	6.9	6025.0	18.0	0.0	4233			
	0	6.5	11.7	2416.7	16.6	11.3	2725.0	26.7	6.5	1879	15.4	8.0	1420.0
	1	6.4	11.6	2416.7	16.5	11.3	2725.0	26.6	6.5	1879	15.2	8.0	1423.3
	2	6.4	11.6	2416.7	16.2	10.8	2725.0	26.6	6.4	1879	15.1	8.0	1423.3
	3	6.4	11.6	2416.7	15.9	10.6	2725.0	26.3	6.3	1879	15.1	7.9	1423.3
	4	6.3	11.6	2416.7	15.7	9.7	2725.0	26.2	6.2	1881	15.1	7.9	1423.3
	5	6.3	11.6	2416.7	15.7	9.3	2725.0	26.0	6.0	1881	15.1	7.9	1423.3
	6	6.3	11.5	2416.7	15.5	8.8	2725.0	25.6	4.9	1931	15.1	7.8	1423.3
	7	6.2	11.4	2416.7	15.3	8.8	2725.0	25.0	2.8	1969	15.1	7.8	1423.3
	8	6.1	11.4	2416.7	15.1	8.5	2725.0	24.1	1.9	2018	15.1	7.8	1423.3
Sta. 4	9	6.1	11.4	2450.0	14.9	8.1	2775.0	22.6	1.4	2156	15.1	7.6	1436.7
	10	6.1	11.3	2483.3	14.8	7.9	2825.0	21.5	1.1	2482	15.1	7.5	1533.3
	11	6.1	11.3	2500.0	14.6	7.8	2925.0	20.6	0.9	2719	15.1	7.1	1776.7
	12	6.1	11.2	2550.0	14.3	7.1	3150.0	19.4	0.8	2930	15.2	6.9	2043.3
	13	7.5	4.2	4333.3	14.1	6.5	3500.0	18.2	0.7	3655	15.7	5.0	2896.7
	14	7.7	4.5	6200.0	13.9	5.4	4900.0	17.3	0.6	4080	15.8	4.2	3800.0
	15	8.2	5.1	7666.7	13.1	3.9	6375.0	16.7	0.6	4230	15.9	3.9	4566.7
	16	7.9	5.5	8633.3	12.6	1.7	7375.0	15.7	0.6	4499	15.4	3.8	1700.0
	17	7.7	8.3	9750.0	11.2	0.0	7875.0	15.5	0.6	4564	15.4	3.8	6333.3
	18	7.2	7.8	10083.3	10.6	0.0	8125.0	15.4	0.6	3965	14.9	3.9	6818.7

VITA

Neil Enoch Carter

Candidate for the Degree of

Master of Science

Thesis: FISH DISTRIBUTION IN KEYSTONE RESERVOIR IN RELATION TO PHYSICOCHEMICAL STRATIFICATION

Major Field: Zoology

Biographical:

Personal Data: Born in Shawnee, Oklahoma, March 9, 1938, the son of Neil H. and Iva Carter.

Education: Graduated from Walters High School, Walters, Oklahoma, in 1956; received Bachelor of Science degree from Oklahoma State University, with major in Zoology in May, 1961; completed requirements for the Master of Science degree, May, 1967.

Professional Experience: U.S. Army Reserve 1961-67; summer fishery survey crew, Oklahoma Wildlife Conservation Department, 1957-58; fishery biologist, Oklahoma Wildlife Conservation Department, 1961-64.