POPULATION DYNAMICS OF FISHES IN FARM PONDS

IN PAYNE COUNTY, OKLAHOMA

By

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PREFACE

The objectives of the present study of population dynamics of fishes in farm ponds were to: (1) estimate various population parameters (i.e. age, growth, survival, standing crop, and production) in ponds in which the fish populations have been established for a number of years; (2) study the interrelationship of physicochemical and biological factors affecting population parameters; (3) provide data that could be used for comparative purposes.

Dr. R. J. Miller served as major adviser. Drs. T. C. Dorris, R. W. Jones, R. D. Morrison and D. W. Toetz served on the advisory committee and criticized the manuscript. V. A. Knudson, F. L. Spangler, J. H. Carroll, W. E. Epperson and F. L. Rainwater helped make field collections. Mr. B. E. Brown and Dr. G. J. Paulik gave helpful advice on the computation of various population parameters. Dr. J. L. Wilhm gave valuable help in criticizing the manuscript. The assistance of all these people is appreciated.

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CHAPTER I

INTRODUCTION

This study was part of a cooperative study on the effect of physicochemical factors on the biota of four farm ponds in north central Oklahoma. Studies on fishes were conducted to determine the interrelationships of these factors and fish population parameters (i.e. age, growth, survival, standing crop and production rate).

There are more than 200,000 farm ponds in Oklahoma with an estimated 340,000 surface acres of water. Farm ponds and Soil Conservation Service Reservoirs will eventually comprise approximately 36 per cent of an estimated 1,263,000 total surface acres of water in Oklahoma. The potential importance of these small bodies of water for recreational, agricultural, industrial and household uses is great and the need for understanding their biology is of utmost importance.

Studies of fishes in Oklahoma farm ponds have been limited mostly to standing crop estimates, with a few exceptions. Irwin (1945) and Irwin and Stevenson (1951) described the nature and cause of turbidity in central Oklahoma waters and presented methods for clearing turbid waters. Wallen (1951) studied the direct effects of clay turbidity on survival of juvenile and adult fishes and concluded clay turbidity is not a lethal factor at concentrations found in nature. Buck (1956) studied the influence of turbidity on fish and fishing in Oklahoma farm ponds, hatchery ponds and reservoirs. Jenkins (1958) estimated the standing crops of fishes in 42 farm ponds and correlated this with some physicochemical factors.

Estimates were made of the survival and net production of fishes in ponds in which the fish populations had been established for a number of years. Net production here is defined as the total growth in weight of fish during the year, including growth in the part of the population which dies before the year ends. Most production studies of farm pond fishes have involved stocking fish in a pond and draining or poisoning at the end of a growing season or at the end of one year, thus obtaining an estimate of the survival rate and the increase in stock weight.

Most of the published information on fish populations and yields is not accompanied by physicochemical data (Rounsefell, 1946). Such data are of considerable value to fishery workers and will eventually lead to a better understanding of the factors influencing fish production.

In the present study I have attempted to present data on the ponds so that other studies may be compared with these. Estimates were made of survival, growth and production rates in ponds in which fish populations have been established for a number of years. The physicochemical factors affecting these population parameters were studied.

If a given fish population ceases to yield enough harvestable size fish to the fisherman, the pond can be drained and refilled (or rotenoned) and then restocked. This is a drastic measure that takes the pond out of production for a year or more. The study of population dynamics may provide us with less drastic means of pond management.

CHAPTER II

DESCRIPTION OF PONDS AND DRAINAGE AREA

The four ponds studied are located about 5 miles north of Stillwater in a mixed-grass prairie in Payne County, Oklahoma. Soils in the area are of Vernon Loam type (U.S. Geol. Survey Prof. Paper) and are derived from Permian sedimentary rocks. Drainage areas are used as native pasture for livestock and the ponds are used primarily for livestock water.

Two of the ponds are turbid and two are clear. The turbid ponds contain 0.32 and 4.91 surface acres at normal water level (Table I) and will be referred to as Little Muddy Pond or (LM) and Big Muddy Pond or (BM), respectively. The clear ponds contain 0.7 and 3.92 surface acres at normal water level (Table I) and will be referred to as Little Clear Pond or (LC) and Big Clear Pond or (BC), respectively. Little Muddy Pond, Big Muddy Pond and Little Clear Pond are located in Range 2E, Township 20N and Section 23, while Big Muddy Pond is located in Range 2E, Township 20N and Section 26. The greatest distance between any two ponds selected for this study is 1 mile.

Little Muddy Pond (Fig. 1) was built about 1947 and redredged in 1956. This pond is oval in shape and contained few aquatic plants. It is located on a hillside and occasionally overflows. The drainage area encompasses 15.0 acres of pasture land where the principle grasses are *Andropogon saccharoides*, *Andropogon scoparius*, *Echinochloa crusgalli*

TABLE I

POND DIMENSIONS

Normal Water Level					
Pond	Volume (Acre-Feet)	Surface Area (Acres)	Mean Depth (Feet)	Length of Shoreline (Feet)	Drainage Area (Acres)
L M	0.49	0.32	1.49	480	15.0
B M	9.12	4.91	1.86	3960	191.5
L C	1.61	0.73	2.19	1070	28.7
B C	10.14	3.92	2.58	2050	27.9

Spillway Level				
Pond	Volume (Acre-Feet)	Surface Area (Acres)	Distance From Water Level to Spillway (Inches)	Drainage Area/Spill-way Vol. Ratio
L M	1.25	0.62	16.52	12.00
B M	14.73	6.94	3.47	13.22
L C	3.95	1.44	28.98	7.07
B C	20.00	5.78	36.19	1.40

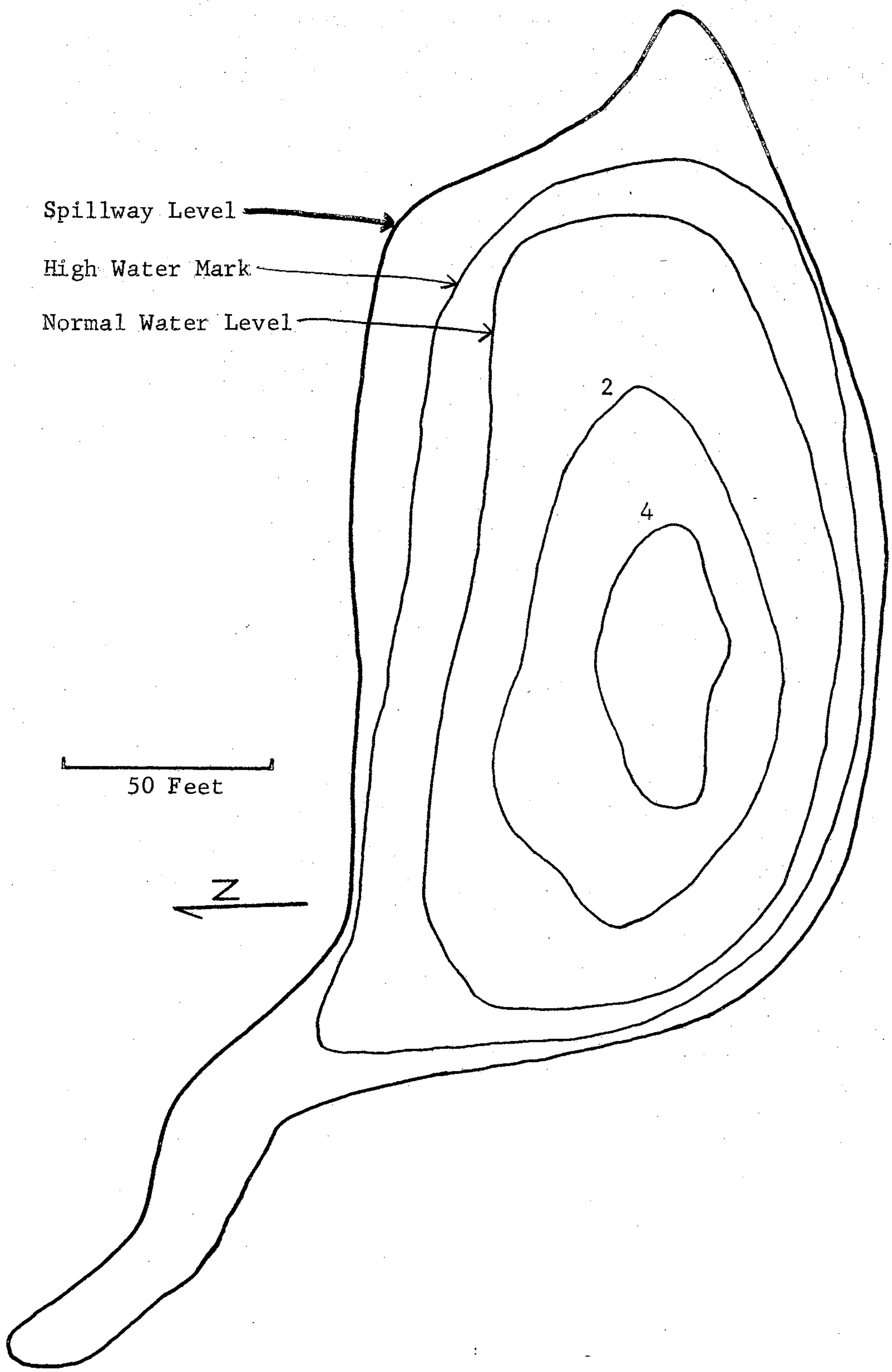

Fig. 1. Map of Little Muddy Pond. Depth contours are in feet below normal water level.

and Aristida oligantha. Common forbs were Ambrosia psilostachya and Solanum eleagnifolium.

Big Clear Pond (Fig. 2) is located about 300 yards from Little Muddy Pond and was built about 1949. Big Clear Pond is located in a ravine. It is partially protected from wind action by steep banks on two sides and it seldom overflows. Aquatic macrophytes were abundant during the warm months and include Potamogeton pectinatus, P. nodosus, Najas guadalupensis and Ceratophyllum demersum. The drainage area is 28.7 acres of native range characterized by Andropogon scoparius, Bouteloua curtipendula, Solidago spp. and Tamarix spp.

Little Clear Pond (Fig. 3), located about 0.2 mile south of Little Muddy Pond, was built about 1942. It was rebuilt in 1956 and the dam was raised in the summer of 1963. Little Clear Pond is a long, narrow pond and lies in a ravine. Najas guadalupensis and Potamogeton spp. were abundant in the summer months. The drainage area is 27.9 acres of well-covered range composed mostly of Andropogon scoparius, A. gerardi, Sorghastrum nutans and Bouteloua hirsuta.

Big Muddy Pond (Fig. 4) is about 1 mile south of the other three ponds and was built about 1930. The pond is irregular in shape and contains few aquatic plants. The water level usually remains close to the spillway level and the pond overflows frequently. The drainage area is 192 acres of overgrazed range, dominated by Andropogon scoparius and Bouteloua hirsuta.

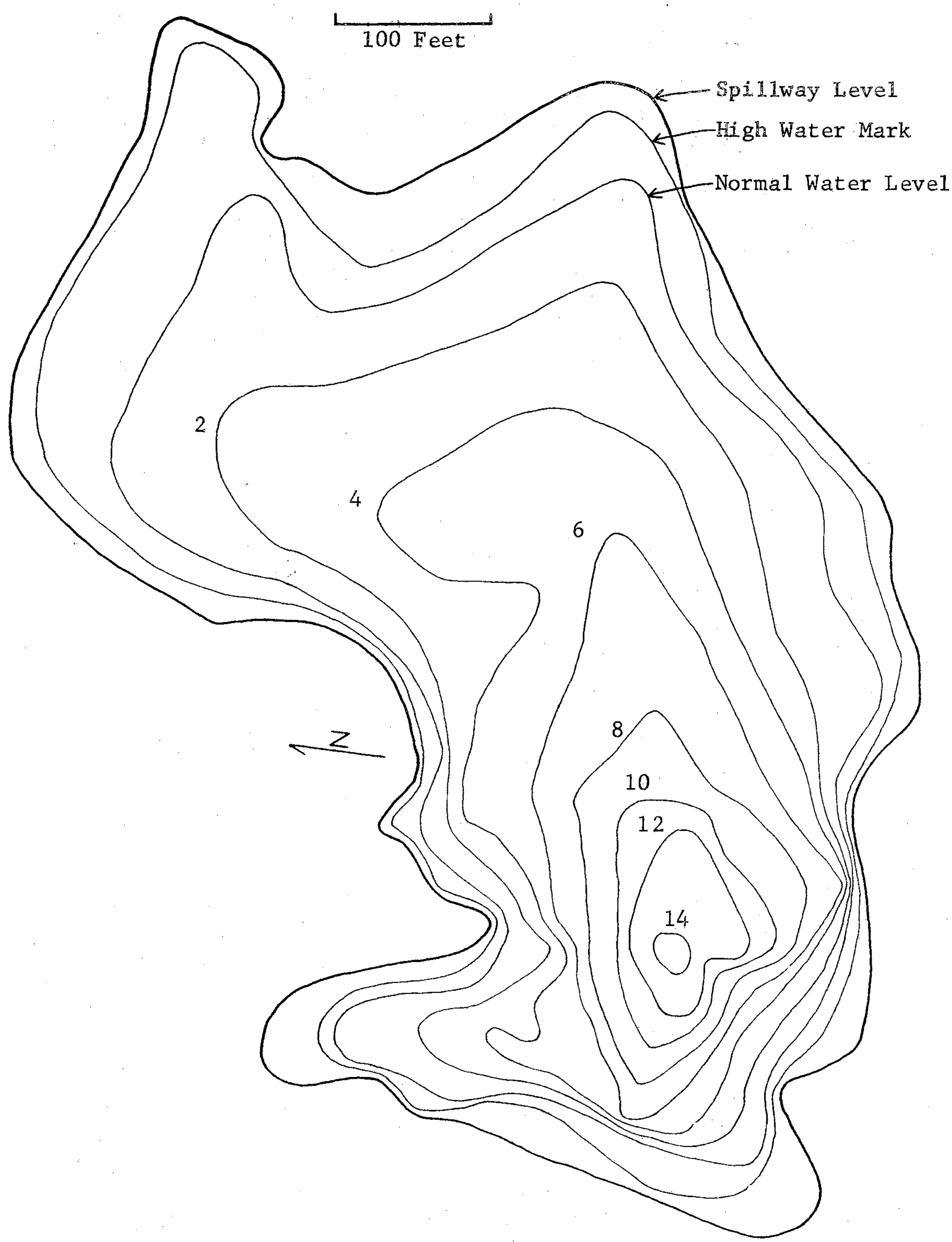

Fig. 2. Map of Big Clear Pond. Depth contours are in feet below normal water level.

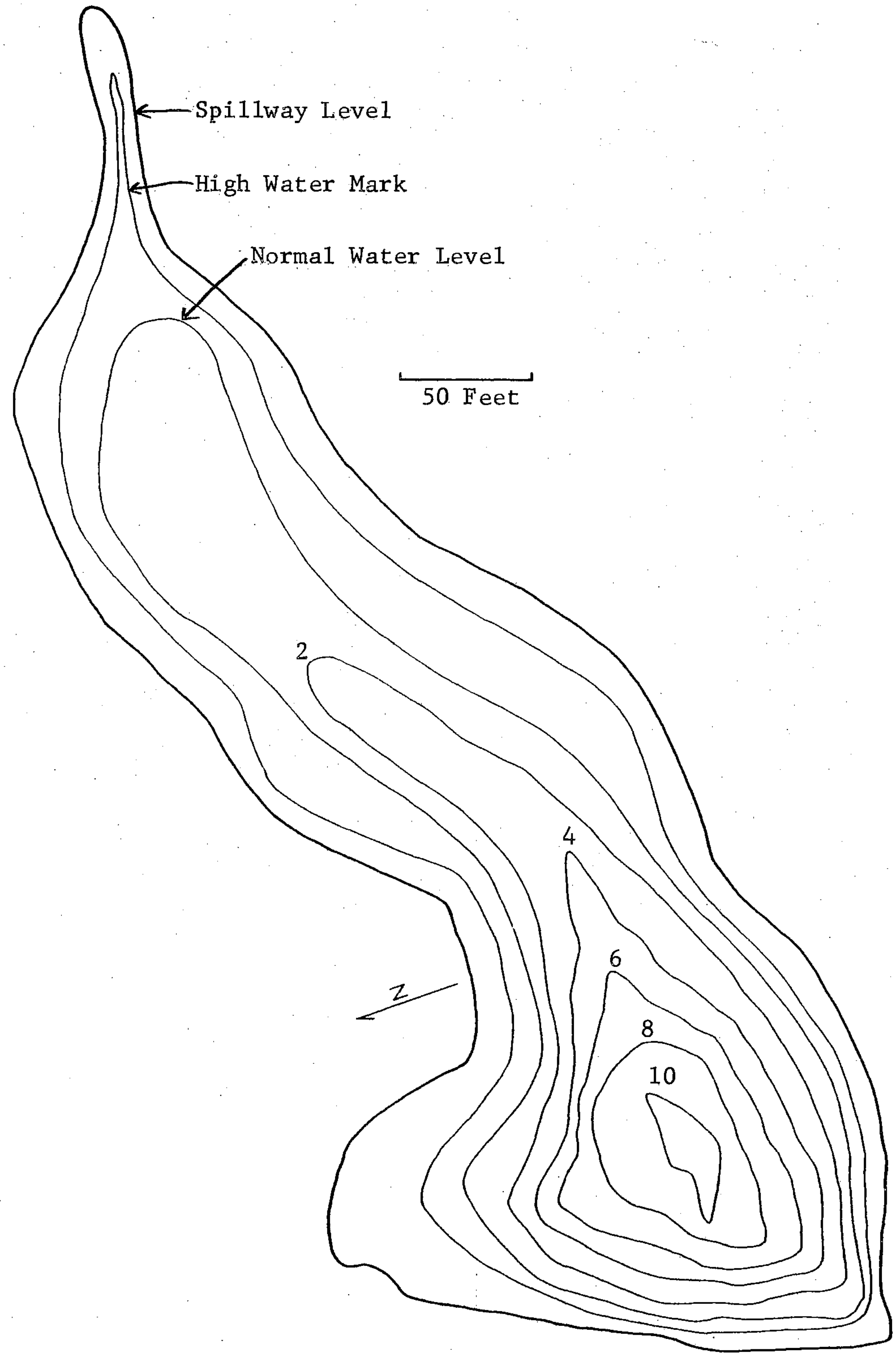

Fig. 3. Map of Little Clear Pond. Depth contours are in feet below normal water level.

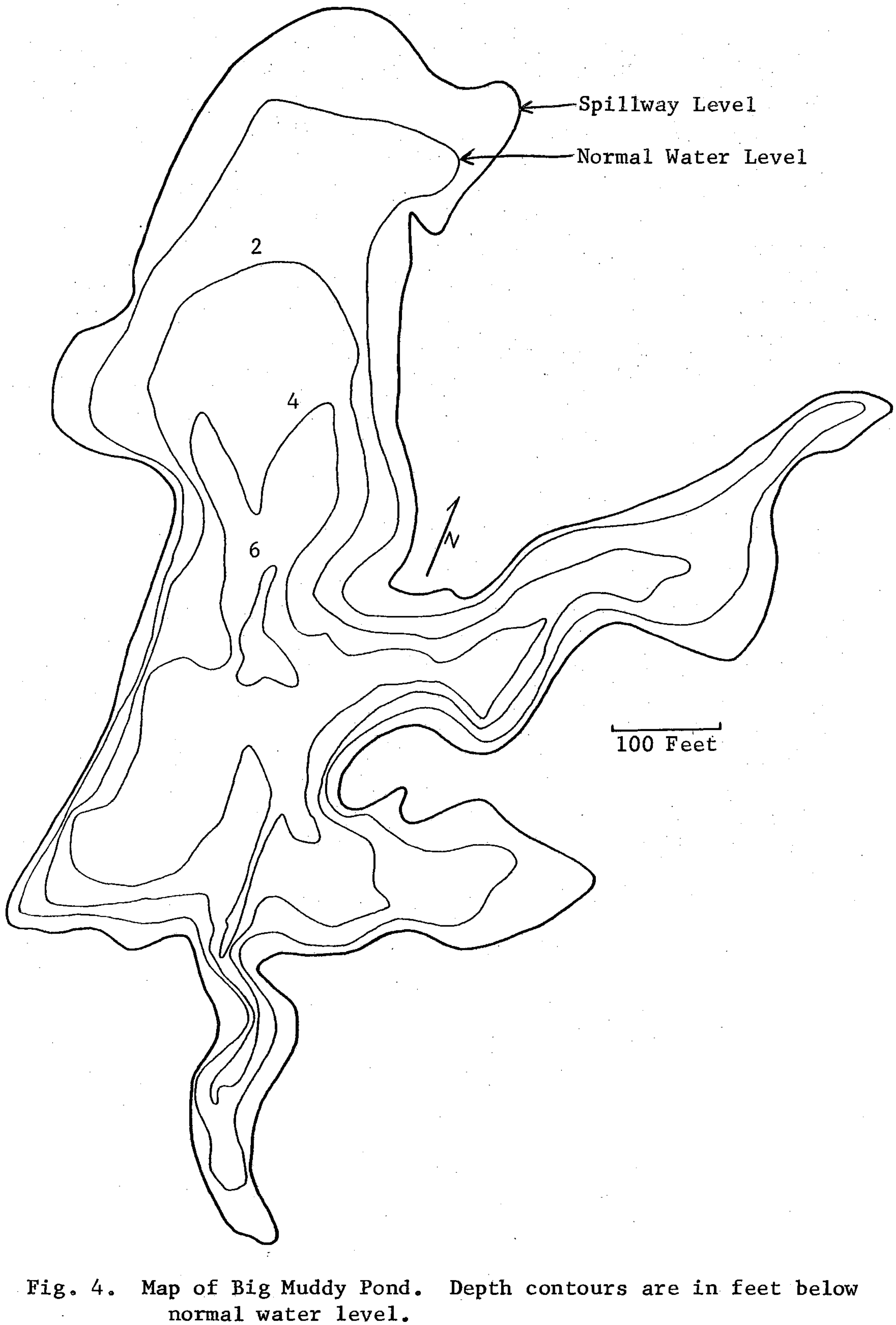

Fig. 4. Map of Big Muddy Pond. Depth contours are in feet below normal water level.

CHAPTER III

METHODS AND MATERIALS

Physicochemical measurements were made on each pond every 2 weeks between September, 1964, and October, 1965. Two ponds were sampled one week and the other two the following week. Water levels were measured with permanent gauges. Rainfall data were obtained from records of the Oklahoma State University weather station. Water temperature was measured with a mercury thermometer or a reversing thermometer. Hydrogen ion concentration was determined by use of a Hellige pH comparator. Per cent transmission of light was measured with a Bausch and Lomb Spectronic 20 Colorimeter and converted to turbidity units (roughly equivalent to mg/liter). Conductivity was determined with a Wheatstone Bridge conductivity meter. Phenolphthalein and methyl orange alkalinity were determined by titration with .02 N sulfuric acid (A.P.H.A., 1960). Depth of light penetration was measured with a Secchi disk. Chemical analyses of the pond waters were made (Tables II, III and IV).

Community respiration and primary productivity were estimated from light and dark bottles incubated for 24 hours. Samples to estimate dissolved and suspended solids were prepared by drying in an oven at 90 C for 24 hours and firing in a furnace at 500 C for 1 hour. Plankton was collected by filtration through millipore filters and chlorophyll and other pigments were extracted in 90% acetone. Pigments were measured in a Bausch and Lomb Spectronic 20 or a Perkins and Elmer recording spectrophotometer. Community respiration, primary productivity, dissolved and suspended solids, chlorophyll, plankton biomass, phytoplankton species diversity and zooplankton species diversity of these ponds are described by Knudson (1967).

TABLE II

TOTAL NITROGEN AND PHOSPHORUS OF POND WATERS, AUGUST, 1965[a]

Pond	Total Nitrogen (ppm)	Total Phosphorus (ppm)
L M	4.00	2.80
B M	1.25	3.60
L C	1.75	0.66
B C	4.50	1.72

[a]Water analyzed by Dr. V. G. Heller of the Oklahoma State University Chemistry Department

The drainage area of each pond was determined from aerial photographs and field observations. Depth contours of the ponds were obtained with a transit and plane tables and the area and volume of the ponds were determined by two methods; cutting contours out and weighing them and by use of an electric grid counter. Both methods gave results within one hundredth of an acre of each other. Average depth of the ponds was determined by dividing the volume of the pond at normal water level by the surface area at normal water level.

Fish collections were made in Little Muddy Pond in June and July, 1965, with a 30-foot bag seine of 1/8 inch mesh. Big Clear Pond was sampled from April through May, 1965, with 20 collapsible nylon fish

TABLE III

CHEMICAL ANALYSES OF FILTERED POND WATERS, MARCH, 1966[a]

Pond	Calcium Hardness (ppm as $CaCO^3$)	Magnesium Hardness (ppm as $CaCO^3$)	Sulfate (ppm as Na_2SO_4)	Orthophosphate (ppm as PO_4)	Total Iron (ppm as Fe)	Nitrate (ppm as NO_3)
L M	48.0	28.0	36.0	0.0	0.3	2.0
B M	72.0	40.0	57.0	0.0	0.1	0.0
L C	63.0	45.0	45.0	0.0	0.0	0.0
B C	56.0	62.0	45.0	0.1	0.1	0.0

[a]Analyzed by Nalco Chemical Company, Chicago, Illinois

traps (Houser, 1960), because extensive aquatic vegetation precluded use of a seine. Big Muddy Pond was sampled from February through July, 1965, and Little Clear Pond from April through May, 1965. Traps and seines were used in sampling the latter two ponds.

TABLE IV

CHEMICAL ANALYSES OF POND WATERS, DECEMBER, 1966[a]

Pond	Chloride (ppm)	Sulfate (ppm)	Calcium (ppm)	Nitrate (ppm)
L M	35.70	44.00	23.00	0.84
B M	53.60	30.00	29.00	0.16
L C	35.70	30.00	25.00	0.24
B C	89.30	10.00	16.00	0.56
Pond	**Magnesium (ppm)**	**Sodium (ppm)**	**Iron (ppm)**	**Mg/Ca (ppm)**
L M	8.00	14.50	4.50	0.35
B M	17.00	20.00	0.50	0.59
L C	15.00	51.00	0.50	0.60
B C	21.00	130.00	0.50	1.31

[a]Analyzed at Oklahoma State University, Soils Laboratory

A direct multiple census was used to estimate population density. All fish taken on the first collection date from each pond were counted and marked by clipping the lower one-fifth of the right pectoral fin, and those not showing signs of distress were returned to the pond. Marked fish taken in subsequent collections were counted, unmarked fish were counted and marked and the sample was returned to the pond. Total length in inches and weight in grams was also measured for each fish.

To avoid bias, I tried to make both the marking and the subsequent sampling random in the population estimates, even though either one alone would suffice. On each collection date the marked fish were returned to different sites in the ponds in order to help assure random distribution. The fish traps were moved to a new site in the pond on each collection date. When seines were used, all seinable areas were sampled.

Removing a fin or fins usually has no immediately fatal effects upon either large or small fishes of the kinds that have been most used in marking experiments (salmonids and centrarchids) (Ricker, 1949). It is assumed that this generalization also applies to the present study.

Scale samples were taken from the fish captured in each pond on the last collection date. Scale impressions were made in heat-softened cellulose acetate and were examined at a magnification of 80 X on a scale reading machine similar to the one described by Van Oosten, Deason, and Jobes (1934). Catfish spines were cross-sectioned and examined under a compound microscope (Sneed, 1950). An ocular micrometer was used to measure the spine cross-sections.

CHAPTER IV

RELATIONSHIP OF PHYSICOCHEMICAL FACTORS

Rainfall and Water Levels

Rainfall in the area was irregular, with largest amounts in November, May, June and September (Table V). Total precipitation during the year of study was 31.42 inches of which over half fell during November, June and September. Less than 1 inch of precipitation/month was received in October, December, January and February.

Big Muddy Pond overflowed in September, March and April. The other ponds did not reach spillway level during the study and gradually decreased in volume from September, 1964, to September, 1965. Decrease in the water level of Big Clear Pond was minimized by seepage from springs near the periphery. Water levels of all ponds fell sharply in late summer during the period of maximum temperature and evaporation. In September, 1965, 6.37 inches of rain fell in 4 days and raised water levels in all of the ponds.

Temperature

Observed temperature of the ponds ranged from 0 to 32 C during the year (Knudson, 1967). Temperature of all ponds fell rapidly from November to December, fluctuated at a low level during the winter months and increased rapidly from March to April. After April, temperatures increased at a slower rate until late July and then began to decrease slowly. The year was divided into a cool season from December through March and a warm season from April through November because of extreme temperature changes in early December and early April and less variable conditions between these times.

TABLE V

MONTHLY RAINFALL DURING THE YEAR OF STUDY AT STILLWATER, OKLAHOMA

Date	Rainfall (Inches)	Date	Rainfall (Inches)
1964		1965	
Oct.	0.54	Apr.	1.92
Nov.	5.28	May	3.78
Dec.	0.64	June	5.28
		July	1.73
1965		Aug.	2.67
Jan.	0.99	Sept.	6.50
Feb.	0.71		
Mar.	1.38	Total	31.42

Mean annual temperatures were similar in all ponds (Table VI). A thermocline was not detected in any pond during the study. Evidently, the ponds were too shallow and the water was too well mixed from wind action for a thermocline to develop.

Conductivity

Conductivity was highest in Big Clear Pond and lowest in Little Muddy Pond in all seasons (Table VI). Values were similar in Little Clear Pond and Big Muddy Pond and intermediate to the other two ponds. Conductivity was inversely related to water level throughout the year. Increased values during spring and late summer appeared to be related to reduced rainfall and concentration of electrolytes by evaporation.

TABLE VI

MEAN ANNUAL AND SEASONAL PHYSICOCHEMICAL CONDITIONS IN THE FOUR PONDS FROM OCTOBER, 1964, TO OCTOBER, 1965

Time	Pond	Conductivity (ppm)	pH	Carbonate (ppm as $CaCO_3$)	Bicarbonate (ppm as $CaCO_3$)	Surface Temperature (C)
Annual means (Oct., 1964, through Oct., 1965)	L M	243	8.0	11.9	85.0	16.8
	B M	361	8.1	0.6	122.5	16.9
	L C	380	8.5	30.1	106.8	16.7
	B C	570	8.8	83.9	146.8	17.0
Cool season means (Dec., 1964, through March, 1965)	L M	209	8.1	0.0	71.2	5.4
	B M	330	8.2	0.0	119.0	2.7
	L C	337	8.3	6.3	136.3	3.4
	B C	563	8.4	5.5	239.5	5.2
Warm season means (April, through Nov., 1965)	L M	257	8.0	2.5	90.8	21.3
	B M	375	8.0	0.8	123.5	23.9
	L C	379	8.6	35.5	100.0	23.3
	B C	579	8.9	110.0	115.9	21.4

An increase of conductivity during the spring in the clear ponds may have been due to increased bicarbonate content (Knudson, 1967).

Hydrogen Ion Concentration and Alkalinity

The pH in the clear ponds during the cool season was slightly higher than in the turbid ponds (Table VI). During early June, pH increased from 8.4 to 9.4 within 10 days in the two clear ponds. In Little Clear Pond, pH remained at this level for 4 weeks and then decreased to 8.6. In Big Clear Pond, pH increased to 9.6 and remained at this point for over 2 months.

Bicarbonate concentration in the clear ponds gradually decreased from a high level in early spring to a lower level during the summer and was less than in the turbid ponds throughout this period. It remained lower in the clear ponds than in the turbid ponds until the last part of August, at which time there was an increase in bicarbonates in all ponds. From the last of August until the first part of October, 1965, bicarbonates decreased in all ponds except in Big Clear Pond where it continued to increase in this pond. In all ponds in early summer the bicarbonates decreased sharply as the carbonate concentration and pH increased, but later in the year, carbonates decreased as the bicarbonate content increased. Maximum carbonate concentrations were 165 ppm in Big Clear Pond and 82 ppm in Little Clear Pond in June, 20 ppm in Little Muddy Pond and 6 ppm in Big Muddy Pond in August. The muddy ponds contained carbonates for about 1 month, while the clear ponds had carbonates for about 7 months. The mean annual carbonate content was greater in clear ponds than in turbid ponds (Table VI).

Photosynthetic processes account for the increase in pH, the decrease in bicarbonates and the increase in carbonates in the clear ponds during the summer months (Knudson, 1967).

Turbidity

Transparency remained high in the clear ponds except for a small decrease during February in Big Clear Pond (Table VII). Little Muddy Pond was always turbid except for an increase in transparency in late summer. In Big Muddy Pond, transparency was highest in February, March, and April. Clear ponds had a smaller drainage area/spillway volume ratio than turbid ponds (Table I).

TABLE VII

MEAN ANNUAL LIGHT TRANSMISSION, TURBIDITY AND SECCHI DISK READINGS FOR THE PONDS, FROM OCTOBER, 1964, TO OCTOBER, 1965

Pond	Transmission (Per Cent)	Turbidity (ppm)	Secchi Disk (Inches)
L M	12.68	247	5.0
B M	38.33	107	5.6
L C	84.47	21	47.4
B C	82.97	23	45.4

Three methods have been described for precipitating turbid particles in Oklahoma ponds. One involves flocculation by hydrogen ions and organic materials (Irwin and Stevenson, 1951). Another involves a salting out process (Keeton, 1959 and Mathis, 1965); while the third is the formation of insoluble hydroxides which appear to be present in the ponds in the present study (Knudson, 1967). The first two mechanisms operate on the principle of disturbing the ionic repulsive charges of the clay particles by addition of cations. The third presumes a "scavenging" action by insoluble carbonates and hydroxides of divalent cations which are produced in quantity by bicarbonate-consuming photosynthesis. Factors affecting turbidity in these ponds are described by Knudson (1967).

Other Ions

The clear ponds contained lowest concentrations of total phosphorus, possibly due to a greater utilization by aquatic macrophytes (Table II). Little Muddy Pond and Big Clear Pond contained the highest concentration of total nitrogen and Little Clear Pond and Big Muddy Pond contained much smaller amounts of nitrogen. Nitrate and orthophosphate were low in March, 1966 (Table III). The sulphate content of all ponds was high, magnesium was more abundant in the clear ponds and the ratio of magnesium to calcium was greater in the clear ponds (Tables III and IV). Iron concentration in Little Muddy Pond was much greater than in the other three ponds (Tables III and IV). The chloride and sodium content of Big Clear Pond was much higher than in the other three ponds (Table IV).

CHAPTER V

POPULATION DYNAMICS

Species Composition

Table VIII is a list of the fishes captured in the four ponds. Five species of fishes were captured from Little Muddy Pond, 12 from Big Muddy Pond, four from Little Clear Pond, and six from Big Clear Pond (Table IX). The greater number of species in Big Muddy Pond might be because this pond is at least 10 years older than any of the other ponds. It also overflows more frequently than the other ponds, thus allowing for better immigration of fish into the ponds. Black bullheads and green sunfish were the most common species in Little Muddy Pond, while white crappie, orangespotted sunfish and black bullheads were the most abundant species in Big Muddy Pond. Largemouth bass and green sunfish were the most abundant species in Little Clear Pond and green sunfish and longear sunfish were the most abundant species in Big Clear Pond.

Length-Weight Relationship

The length-weight relationship was calculated for each species of fish in each pond (Table X). The logarithmic expression of the relationship of length to weight results in the equation:

$$\ln W = a + b \ln L$$

TABLE VIII

LIST OF FISHES COLLECTED FROM THE FOUR PONDS

Common Name	Abbreviations	Scientific Name
White crappie	W C	*Pomoxis annularis*
Black crappie	B C	*P. nigromaculatus*
Green sunfish	G S	*Lepomis cyanellus*
Longear sunfish	L E	*L. megalotis*
Orangespotted sunfish	O S	*L. humilis*
Bluegill	B G	*L. macrochirus*
Redear sunfish	R E	*L. microlophus*
Largemouth bass	L M B	*Micropterus salmoides*
Black bullhead	B B	*Ictalurus melas*
Channel catfish	C C	*Ictalurus punctatus*
Golden shiner	Au S	*Notemigonus crysoleucas*
Red shiner	R S	*Notropis lutrensis*
Mosquitofish	M F	*Gambusia affinis*

TABLE IX

MEANS AND RANGES OF LENGTH AND WEIGHT OF FISHES IN ALL COLLECTIONS THAT WERE UNMARKED AT TIME OF CAPTURE

Pond	Spp.[a]	Number Fish in Sample	Mean Length (Inches)	Length Range (Inches)	Mean Weight (Grams)	Weight Range (Grams)	Mean Weight[b] (Grams)
L M	G S	494	4.0	2.8-6.4	18.79	5-71	18.79
	B B	38	6.5	2.2-8.4	69.05	2-140	69.05
	L E	9	4.0	3.5-4.3	23.67	12-33	23.67
	W C	1	14.5	14.5	1107.00	1107	1107.00
B M	W C	1646	4.6	1.0-11.6	17.75	1-334	18.22
	G S	14	4.1	2.7-5.0	20.29	6-38	20.29
	L M B	73	2.4	1.5-11.0	14.15	1-288	27.48
	B B	609	4.9	2.9-12.8	28.58	3-220	28.58
	L E	95	3.6	1.7-5.5	15.96	2-52	15.96
	O S	263	2.5	1.5-4.5	5.01	1-28	5.01
	B G	137	4.4	1.8-5.5	23.12	2-49	23.12
	R E	166	4.4	2.6-7.6	22.82	4-106	22.82
	C C	20	7.3	1.6-16.8	83.75	1-680	83.75
	Au S	59	4.3	1.2-6.8	15.03	1-41	15.03
	M F	7	1.6	1.0-2.0	1.14	1-2	1.14
	R S	3	2.6	1.9-3.0	3.33	1-5	3.33
L C	G S	516	3.7	0.9-8.0	28.23	1-135	32.86
	L M B	156	5.8	2.8-15.2	60.75	5-738	63.27
	B B	29	12.0	11.0-12.8	389.48	245-499	389.48
	B C	1	4.5	4.5	12.00	12	12.00
B C	W C	20	10.2	7.4-12.1	262.35	95-368	262.35
	G S	614	4.7	1.0-8.5	41.55	1-215	41.55
	L M B	93	4.9	1.0-13.2	65.27	1-592	80.90
	B B	11	11.1	8.0-15.2	472.27	167-1020	472.27
	L E	86	3.9	2.0-6.4	32.20	3-120	32.20
	C C	1	24.0	24.0	2799.00	2799	2799.00

[a]For abbreviations, refer to Table VIII.

[b]Average weights used in calculating biomass estimates. These averages have young-of-year fish removed.

TABLE X

LENGTH-WEIGHT RELATIONSHIPS[1]

Pond	Species[2]	Length-Weight Relationship[3]	Correlation Coefficient of ln L vs Ln W	Number Fish in Sample
L M	G S	ln W = -0.91275 + 2.73949 ln L[a]	0.960	494
	B B	ln W = -1.86503 + 3.13738 ln L[a]	0.996	38
	L E	ln W = -2.70905 + 4.22604 ln L[a]	0.924	9
B M	W C	ln W = -1.16284 + 2.57526 ln L[a]	0.925	1646
	G S	ln W = -0.43226 + 2.39687 ln L[a]	0.876	14
	L M B	ln W = -1.17083 + 2.75080 ln L[a]	0.960	73
	B B	ln W = -2.14924 + 3.26867 ln L[a]	0.980	609
	L E	ln W = -1.09853 + 2.91518 ln L[a]	0.967	95
	O S	ln W = -0.83625 + 2.49814 ln L[a]	0.895	263
	B G	ln W = -1.21007 + 2.91843 ln L[a]	0.946	137
	R E	ln W = -1.30991 + 2.95997 ln L[a]	0.967	166
	C C	ln W = -1.94604 + 2.92212 ln L[a]	0.987	20
	Au S	ln W = -1.26997 + 2.53239 ln L[a]	0.982	59
	M F	ln W = -0.16774 + 0.59084 ln L[c]	0.490	7
	R S	ln W = -2.10486 + 3.27934 ln L[b]	0.992	3
L C	G S	ln W = -0.79027 + 2.72066 ln L[a]	0.988	516
	L M B	ln W = -1.70136 + 2.97114 ln L[a]	0.978	156
	B B	ln W = -3.01345 + 3.61032 ln L[a]	0.824	29
B C	W C	ln W = -1.26426 + 2.93090 ln L[a]	0.876	20
	G S	ln W = -1.23357 + 3.01206 ln L[a]	0.972	614
	L M B	ln W = -0.57429 + 2.36295 ln L[a]	0.967	93
	B B	ln W = -1.05158 + 2.90338 ln L[a]	0.981	11
	L E	ln W = -1.53557 + 3.40185 ln L[a]	0.991	86

[1]W = weight in grams and L = total length in inches; based on unmarked fish at time of capture.

[2]For abbreviations, refer to Table VIII.

[3]Slope of the line of the length-weight relationship is significantly different from zero at the 00.1% level (a); at the 10% level (b); and at the 30% level (c).

where W = weight in grams, L = total length in inches and ln = natural logarithm. The slopes of the lines of all the length-weight relationships are significantly different from zero at the 00.1% level, except for the mosquitofish and the red shiner, which were significant at the 30 and 10% levels respectively. The low significance level of the mosquitofish might be caused by bias in weighing extremely small fish. This bias was of particular importance since all of these fish sampled were nearly the same size. The low significance level of the red shiner might be due to having only one degree of freedom. The simple correlation coefficient between ln of length and ln of weight was also calculated for each species of fish in each pond (Table X). A high positive correlation existed for all species except the mosquitofish, which had a low correlation coefficient of 0.49.

Aging Fish

If the body-scale relationship is linear over the total range in which back-calculation is to be attempted, then the Lee method (Lagler, 1956) may be used for this purpose. The only statistic necessary for the Lee method is the intercept on the Y or body length axis. Regier (1962) studied the validation of the scale method for estimating age and growth of bluegills in New York farm ponds. He compared the intercepts of body-scale relationships from individual ponds with a mean intercept from all ponds and concluded that for practical purposes it was valid to use a mean intercept from body-scale relationships for his 24 ponds in back-calculations. When the data permitted, a mean intercept was used for all ponds (Table XI). Thus, the intercepts were based upon a much larger sample than if individual pond intercepts had been used.

In the present study, a least-squares line was computed for the body-scale relationship of each species in each pond (Table XI). The resulting equations for body-scale relationships are of the form $Y = a + b X$, where X is the scale radius in millimeters times 80 for scaled fish and spine radius in millimeters times 100 for catfish, Y is total length of the fish in tenths of inches, a is the Y intercept and b is the slope (Table XI). The slope of the lines of all the body-scale relationships were significantly different from zero at the 00.1% level. High positive correlation coefficients were found for body length and scale radius (Table XI).

TABLE XI

BODY-SCALE RELATIONSHIPS[a, b]

Pond	Spp.	Body-Scale Relationships	Correlation Coefficient	No. in Sample
B M	W C	Y = 1.42488 + 0.02756 X	0.933	42
	O S	Y = 0.90131 + 0.01701 X	0.976	12
	B G	Y = 1.20955 + 0.01725 X	0.796	16
	R E	Y = 0.37292 + 0.01930 X	0.945	23
	Au S	Y = 0.84099 + 0.02683 X	0.943	11
	C C	Y = 0.39425 + 0.06496 X	0.936	8
c	G S	Y = 0.38956 + 0.02682 X	0.918	66
c	L M B	Y = 0.66431 + 0.03213 X	0.955	20
c	L E	Y = 0.31816 + 0.02236 X	0.974	17
c	B B	Y = 0.83074 + 0.05418 X	0.923	18

[a]X is scale radius in mm times 80 magnification for scaled fish and spine radius in mm times 100 for catfish, Y is total length in inches.

[b]The slopes of the lines of all body-scale relationships were significantly different from zero at the 00.1% level.

[c]Fish from all ponds combined

Mean calculated total lengths in inches at the end of each year of life for each species in each pond is given in Table XII.

Growth Rates

Growth rates were based on the average growth rate of the fish from one year of age to the oldest aged fish for that species (Table XII). Age was estimated from scale readings. Young-of-year fish were not included in these growth rates, since few were captured and since they were not included in standing crop estimates. Since identities of individual fish were not maintained from one sampling period to the next, mean length $(\bar{l})$ or mean weight $(\bar{w})$ of the fish population at a particular time was the basic unit used in growth determinations. The measure of length increments in a pond population between time "o" and time "t" was $(\Delta \bar{l}) = \bar{l}_t - \bar{l}_o$. The mean length at one year of age (Table XII) was set equal to $\bar{l}_o$ and the mean length of the oldest fish aged for that species in a given pond was set equal $\bar{l}_t$. Similarly, the coefficient of growth (instantaneous growth rate), g, was determined from means rather than from individual fish. Mean length was converted to mean weight from the length-weight relationship equations (Table X). The latter values were used in the equation for the instantaneous mean growth rate:

$$\bar{g} = \ln(\bar{w}_t/\bar{w}_o)$$

where $\bar{w}_o$ and $\bar{w}_t$ are mean weights of fish in the population at time "o" and "t" respectively and ln is the natural logarithm (Eipper, 1964). This value is not strictly comparable to a mean of instantaneous growth

TABLE XII

MEAN CALCULATED TOTAL LENGTH AT THE END OF EACH YEAR OF LIFE, 1965

		Age Groups					
Pond	Spp.	1	2	3	4	5	6
L M	G S	1.77 (33)[a]	2.83 (33)	3.62 (29)	4.35 (14)	4.70 (14)	5.40 (1)
	L E	1.40 (2)	2.72 (2)	3.30 (2)			
	B B	2.78 (5)	4.22 (4)	5.75 (4)	6.50 (1)		
B M	W C	3.12 (37)	4.06 (22)	4.71 (5)			
	L M B	4.88 (2)	7.75 (2)				
	L E	1.58 (15)	2.44 (12)	3.04 (9)	3.35 (1)		
	B G	2.39 (16)	3.15 (16)	3.68 (15)	4.14 (10)	4.70 (1)	
	Au S	3.81 (8)	4.99 (7)	5.05 (2)	5.65 (1)		
	G S	1.87 (5)	2.62 (5)	3.33 (5)	4.20 (2)	4.70 (1)	
	O S	1.65 (12)	2.24 (9)	2.72 (2)	3.15 (1)		
	R E	1.78 (24)	2.87 (22)	3.67 (18)	4.18 (16)	4.97 (3)	
	B B	2.38 (6)	4.69 (4)				
	C C	5.05 (7)	8.80 (5)	11.78 (3)	14.88 (2)	16.4 (1)	17.6 (1)
L C	G S	1.94 (22)	3.19 (22)	4.00 (21)	4.72 (19)	5.90 (9)	
	L M B	3.85 (6)	4.90 (1)				
	B B	5.26 (5)	7.27 (5)	8.62 (4)	9.63 (3)		
B C	G S	1.45 (6)	2.74 (5)	4.36 (3)	5.52 (2)	6.32 (2)	
	L M B	4.64 (9)	7.85 (2)	10.98 (2)	10.40 (1)		
	B B	6.15 (2)	9.00 (2)	12.48 (2)	12.30 (1)		

[a]Number of fish in parenthesis

rates of individual fish. Division of this $\bar{g}$ by the interval of time in years for which the growth rate is based, will produce an average annual instantaneous mean growth rate "$\bar{\bar{g}}$" (Table XIII).

TABLE XIII

ESTIMATED AVERAGE INSTANTANEOUS MEAN GROWTH RATE ($\bar{\bar{g}}$)
(Estimates are for fish from one year old to oldest fish aged for that species.)

Pond	Spp.	$\bar{\bar{g}}$	Mean Relative Growth Rate "$\bar{h}$" Calc. From $\bar{\bar{g}}$	No. Years That $\bar{\bar{g}}$ and $\bar{h}$ are an Average for
L M	G S	0.60064	0.8239	5
	L E	1.81000	5.1104	2
	B B	0.88790	1.4303	3
B M	W C	0.53000	0.6989	2
	L M B	1.27100	2.5609	1
	L E	0.72991	1.0751	3
	B G	0.50000	0.6487	4
	Au S	0.33232	0.3938	3
	G S	0.55223	0.7367	4
	O S	0.53887	0.7143	3
	R E	0.30186	0.3526	4
	B B	2.21703	8.2070	1
	C C	0.72988	1.0751	5
L C	G S	0.75687	1.1297	4
	L M B	0.71500	1.0442	1
	B B	0.73351	1.0834	3
B C	G S	1.10830	2.0344	4
	L M B	0.63270	0.8833	3
	B B	0.67070	0.9562	3

The average annual instantaneous mean growth rate was calculated for the fishes aged life span instead of calculating an instantaneous mean growth rate for each year of life, because the rates were used in estimating production rates for all age groups combined instead of for each age group separately. Also, the logarithm of mean weight at each age was plotted for a few species of fishes and this resulted in an acceptable straight line. Thus, growth rates were calculated over all age groups instead of taking an average of growth rates for each age group. Calculation of the instantaneous mean growth rate for green sunfish in Little Clear Pond is set out below as an example of the procedure used. The lengths, $\bar{l}_1$ = 1.94 inches and $\bar{l}_5$ = 5.90 inches (Table XII), were used to learn the weights of the fish, $\bar{w}_1$ = 2.75 g and $\bar{w}_5$ = 56.8 g, from the length-weight relationship equation for this species (Table X). The instantaneous mean growth rate, $\bar{g}$, for the four year interval (year one to year five) is

$$\ln(\bar{w}_5/\bar{w}_1) = 3.0275.$$

The average annual instantaneous mean growth rate ($\bar{\bar{g}}$) is 3.0275/4 = 0.7569.

The average annual instantaneous mean growth rate ($\bar{\bar{g}}$) was converted to mean annual growth rate ($\bar{h}$) or relative rate of growth by using the equation,

$$\bar{h} = e^{\bar{\bar{g}}} - 1 \qquad \text{or} \qquad \bar{h} = (\bar{w}_t - \bar{w}_o/\bar{w}_o)/(t-1)$$

where t is the upper age of the species (Table XIII) (Ricker, 1958).

Annual growth rates of green sunfish, based on four or five year classes were greater in Little Clear Pond, 1.1297, and Big Clear Pond, 2.0344, than in Little Muddy Pond, 0.8239, and Big Muddy Pond, 0.7367 (Table XIII). The mean annual growth rates of black bullheads in Little Muddy Pond, 1.4303, and Big Muddy Pond, 8.2070, were greater than in Little Clear Pond, 1.0834, and Big Clear Pond, 0.9562 (Table XIII).

Since these fish are largely chemosensory feeders they may have an advantage over sight feeders in competing for food in turbid ponds.

Survival and Mortality Rates

The age-frequency distribution in a population typically presents a descending staircase appearance. The basic idea underlying catch-curve analysis is that the decrease in frequency from one age group to the next reflects the combined effects of the difference in initial year-class strength for the different age groups and mortality. Unbiased estimates of annual survival rate may be derived from a catch curve for a single season if assumptions of constant year-class strength and survival rate holds true and if all fish beyond some minimum age are equally vulnerable to the sampling gear (Chapman and Robson, 1960). Since all four ponds contained fish for several years and had more or less reached an equilibrium state, equal year-class strength for each species in each pond was assumed. Annual survival rates for each species in each pond were assumed to be constant for the age groups considered fully recruited to the method of capture. The age at which a species in a given pond was considered fully recruited to the method of capture was the youngest age for which the catch was larger than the next older age group.

The difficulty of age determination by the scale reading method increases with age of the fish. One way to reduce aging errors is to attempt exact aging only for the younger age groups and combine remaining age groups (Robson and Chapman, 1961). This technique sacrifices some potential information contained in the sample, but the ease of operation permits use of larger samples.

Survival rate and its variance were calculated according to the method of Robson and Chapman (1961). If fish through K years of age are aged exactly and all fish K + 1 years old or older are grouped, then the tabulated age-frequency distribution will take the form:

Coded Age	Number in Catch
0	N_0
1	N_1
2	N_2
.	.
.	.
.	.
K	N_K
K + 1 or older	m

The initial age used in this estimation is coded as zero, the next age is coded as 1, etc. The best maximum likelihood estimate of annual survival rate in this case depends on T and the total sample size n:

$$T = N_1 + 2N_2 + 3N_3 + \ldots + KN_K + m(K + 1)$$
$$n = N_0 + N_1 + N_2 + \ldots + N_K + m$$

and takes the form,

$$\hat{s} = T/(n - m + T)$$

where $\hat{s}$ is an estimate of the annual survival rate. The variance of this estimate, under the assumption that no errors are committed in this modified age-classification technique, is

$$\sigma_s^2 = s(1 - s)^2/n(1 - s^{K+1})$$

where s is the true survival rate in the population being sampled.

Survival rates for each species in each pond (Table XIV) were estimated by using a program (Analysis of a Catch Curve) written by L. E. Gales and G. J. Paulik, College of Fisheries, University of Washington, based upon Robson and Chapman methods. The program also permits computation of total instantaneous mortality rates (i) with a correction term for bias as well as 95% confidence intervals for i (Table XIV). The correction term for bias is included in brackets in the following equation for an estimate of total instantaneous mortality rate:

$$\hat{i} = -\ln \hat{s} - \left[(1 - \hat{s})^2/n\hat{s}(1 - \hat{s}^{K+1})\right].$$

The variance of i is

$$\sigma_i^2 = (1 - \hat{s})^2/n\hat{s}(1 - \hat{s}^{K+1})$$

which is the same as the correction term for bias in the equation above. The 95% confidence interval is computed using the lower limit as two standard deviations below the estimate of i and the upper limit as two standard deviations above it (G. J. Paulik, Personal Communication). Annual mortality rate (a) was calculated using the following equation: $\hat{a} = 1 - \hat{s}$ (Table XIV).

To determine the length interval of an age group of a certain species in a given pond, the midpoints between successive age groups (Table XII) were found, and the interval between two midpoints was

TABLE XIV

ESTIMATED ANNUAL SURVIVAL, MORTALITY AND TOTAL INSTANTANEOUS MORTALITY RATES
(Obtained from a catch curve program written by L. E. Gales and G. J. Paulik and based on methods from Chapman and Robson, 1960, and Robson and Chapman, 1961)

Pond	Spp.	Estimated Survival Rate ($\hat{s}$)	95% Confidence Intervals for $\hat{s}$ Lower Limit	95% Confidence Intervals for $\hat{s}$ Upper Limit	Age at Full Re-cruitment	Est. Total Instant. Mort. Rate ($\hat{i}$)	95% Confidence Intervals for $\hat{i}$ Lower Limit	95% Confidence Intervals for $\hat{i}$ Upper Limit	Estimated Annual Mort. Rate ($\hat{a}$)	Number of Fish Calculations Based on
L M	G S	0.3955	0.3552	0.4358	3	0.9250	0.8230	1.0270	0.6045	421
	B B	0.9307	0.8814	0.9800	1	0.0711	0.0182	0.1241	0.0693	38
B M	O S	0.5994	0.5452	0.6537	2	0.5098	0.4193	0.6003	0.4006	204
	B G	0.5620	0.4718	0.6522	3	0.5698	0.4093	0.7304	0.4380	121
	W C	0.8993	0.8837	0.9148	2	0.1061	0.0888	0.1234	0.1007	1449
	G S	0.7000	0.4102	0.9898	4	0.3138	-0.1002	0.7279	0.3000	10
	L M B	0.3077	0.0517	0.5637	1	1.0056	0.1735	1.8376	0.6923	13
	R E	0.4015	0.3162	0.4868	4	0.9012	0.6887	1.1137	0.5985	132
	C C	0.3125	0.0871	0.5379	2	1.0331	0.3120	1.7543	0.6875	12
	Au S	0.7304	0.6516	0.8093	1	0.3112	0.2033	0.4191	0.2696	33
L C	G S	0.7188	0.6936	0.7440	1	0.3299	0.2948	0.3650	0.2812	487
	L M B	0.7134	0.6412	0.7856	1	0.3352	0.2340	0.4364	0.2866	157
B C	G S	0.5260	0.4888	0.5633	3	0.6412	0.5703	0.7120	0.4740	471
	L M B	0.3168	0.2262	0.4075	1	1.1289	0.8428	1.4150	0.6832	80
	B B	0.4545	0.1543	0.7548	2	0.6794	0.0188	1.3400	0.5455	11

considered as the range of that age group. The unmarked fish from all collection dates in a pond were placed in their appropriate age groups by using the above length intervals. All fish in the total catch with total lengths greater than the midpoint between the last two age groups shown in Table XII for each species in each pond, were grouped together and entered as the K + 1 or older age group.

The annual survival rates of green sunfish were 0.3955 in Little Muddy Pond, 0.7000 in Big Muddy Pond, 0.7188 in Little Clear Pond and 0.5260 in Big Clear Pond. Since the sample size for green sunfish in Big Muddy Pond was only 10, the estimated annual survival rate may be inaccurate.

Largemouth bass had a higher annual survival rate in Little Clear Pond (0.7134) and Big Clear Pond (0.3168) than in Big Muddy Pond (0.3077) (Table XIV). This may partially be accounted for by largemouth bass having difficulty capturing prey in the turbid ponds; however, this difficulty may also exist in the clear ponds because of aquatic vegetation. Buck (1956) found that the survival rate for bass was lower in turbid than in clear hatchery ponds in Oklahoma. Regier (1963a) found that in bass-shiner ponds in New York, the mean bass survival rates in the absence of fishing were about 83% per year for the first 2.3 years, and about 94% the next 2.7 years. Corresponding estimates for bass-bluegill ponds were 80% for the first 5 years. About 70% of the bass and 75% of the bluegills survived for the first year following stocking, in experimental ponds in Alabama (Swingle, 1950). The annual survival rate of largemouth bass in Little Clear Pond (0.7134) was similar to the survival rates of the other authors, but the annual survival rates in Big Clear Pond (0.3168) and Big Muddy Pond

(0.3077) were lower.

Annual survival rate of black bullheads was higher in Little Muddy Pond (0.9307) than in Big Clear Pond (0.4545). This might be partially accounted for because bullheads could escape from their predators more easily in the turbid ponds.

The annual survival rate of channel catfish in Big Muddy Pond was 0.3125. Channel catfish survival was higher in turbid than in clear Oklahoma hatchery ponds (Buck, 1956). The estimated annual survival rate of channel catfish to age II+ in New York farm ponds was found to vary from 0.0 to .92 (Regier, 1963b). The mean annual survival rate of all species in all ponds was 0.5712.

Standing Crop Estimates

The standing crop in numbers and pounds per surface acre and per acre foot for each species in each pond (Table XV) was estimated by the Chapman (1954) modification of the Schnabel method. Chapman's equation with its correction for bias is as follows:

$$N = \sum_{i=1}^{k} C_i M_i / \sum_{i=1}^{k} R_i + 1$$

where

N is the estimate of population size in numbers,

C_i is the total number captured in the i^{th} day,

M_i is the number of marked animals in the population on the i^{th} day (prior to the trapping on that day),

R_i is the number of marked animals captured in the i^{th} day,

k is the number of different collections made.

TABLE XV

STANDING CROP ESTIMATES AND CONFIDENCE INTERVALS

Pond	Species	No. Fish/Pond	95% Confidence Intervals on No. Fish/Pond Lower Limit	Upper Limit	Wt. Fish/Pond (lbs)	No. Fish/Sur. Acre at Normal Level	Wt. Fish/Sur. Acre at Normal Level (lbs)	No. Fish/Acre Ft. at Normal Level	Wt. Fish/Acre Ft. at Normal Level (lbs)
L M	L E	29	7[a]	245	1.51	91	4.73	60	3.12
	B B	145	43[a]	711	22.00	452	68.74	298	45.35
	G S	685	677[b]	694	28.38	2,141	88.69	1,413	58.52
	W C	1	c		2.44	3	7.63	2	5.03
	C C	1	c		0.94	3	2.95	2	1.94
Total		861			55.27	2,690	172.74	1,775	113.96
B M	W C	12,755	12,536[b]	12,982	512.30	2,598	104.34	1,398	56.16
	O S	1,167	768[a]	1,808	12.89	238	2.62	128	1.41
	B B	2,422	2,376[b]	2,481	152.57	493	31.07	265	16.73
	M F	9	1[a]	331	0.02	2	0.004	1	0.002
	G S	4	6[a]	1,676	1.92	9	0.39	5	0.21
	L M B	427	98[a]	3,617	25.89	87	5.27	47	2.84
	L E	925	319[a]	3,412	32.53	188	6.63	101	3.57
	R E	457	310[a]	683	22.98	93	4.68	50	2.52
	B G	725	396[a]	1,385	36.95	148	7.53	79	4.05
	R S	3	c		0.02	1	0.004	<1	0.002
	C C	20	c		3.69	4	0.75	2	0.04
	Au S	58	c		1.92	12	0.39	6	0.21
Total		18,971			802.68	4,042	163.68	2,082	87.74
L C	B B	68	24[a]	252	58.56	93	80.20	42	36.42
	L M B	221	183[b]	279	30.80	302	42.19	137	19.15
	G S	660	620[b]	706	47.79	904	65.47	410	29.72
	B C	1	c		0.03	1	0.04	<1	0.02
Total		882			137.18	1,300	187.90	589	85.31
B C	W C	35	16[a]	86	20.17	9	5.15	3	1.97
	L M B	259	123[a]	596	46.15	66	11.77	26	4.55
	L E	650	224[a]	2,397	46.11	166	11.76	64	4.55
	G S	1,428	1,235[b]	1,679	130.78	364	33.36	141	12.90
	C C	1	c		6.17	<1	1.57	<1	0.61
	B B	11	c		11.45	3	2.92	1	1.13
Total		2,384			260.83	608	66.53	235	25.71

[a]Chapman and Overton (1966) table was used.

[b]Paulik method used

[c]This is the actual number of fish caught and there were no recoveries for this species. Insufficient data for confidence intervals.

When there were no recoveries for a given species in a given pond, the total number and weight of that species captured in all collections were used as estimates of standing crop (Table XV). Estimates of biomass were obtained by multiplying the mean weight of a given species in a particular pond (Table IX) by the estimate of population density. Although the method requires that the population be constant with no recruitment or mortality during the duration of the study, it is often useful if these conditions are only approximately satisfied (Ricker, 1958).

Confidence intervals for the standing crop estimates (Table XV) were obtained by two methods. When the $\sum_{i=1}^{k} R_i$ was less than or equal to 50, Table 1 in Chapman and Overton (1966) was used to obtain confidence limits. When the $\sum_{i=1}^{k} R_i$ was greater than 50 the following equation was used to obtain confidence limits:

$$\widehat{(1/N)} - \left| z_{\alpha/2} \right| \sqrt{\sum_{i=1}^{k} R_i} \Big/ \sum_{i=1}^{k} C_i M_i < 1/N < \widehat{(1/N)} + \left| z_{1-\alpha/2} \right| \sqrt{\sum_{i=1}^{k} R_i} \Big/ \sum_{i=1}^{k} C_i M_i$$

where α is the probability level and z is the standard normal deviate and where the portion on the left side of 1/N is the lower limit and that on the right side is the upper limit (G. J. Paulik, Personal Communication). This equation is based on the assumption that for large numbers of recoveries the distribution of the sums of the recoveries approximates a normal distribution. Instead of computing confidence limits directly for N, it is better to compute them for the more symmetrically distributed (1/N) (Ricker, 1958). To obtain limits for N from the preceding equation, the following calculation is used:

$$\frac{1}{\text{Upper Limit}} < N < \frac{1}{\text{Lower Limit}}$$

Standing crop estimates in pounds/surface acre at normal water level were 173 in Little Muddy Pond, 164 in Big Muddy Pond, 188 in Little Clear Pond, 67 in Big Clear Pond, and a mean of 148 for all four ponds. In a study of 42 Oklahoma ponds, Jenkins (1958) found a mean standing crop of 341 pound/acre and a range from 57 to 931. Buck (1956) in a study of 12 Oklahoma ponds estimated average standing crops of 162 pounds/acre in clear ponds ($<$ 25 ppm turbidity), 94 in intermediate ponds (25-100 ppm turbidity) and 29.3 in muddy ponds ($>$100 ppm turbidity). Sandoz (1960) found a mean standing crop of 121 pounds/acre in four Oklahoma farm ponds and a range from 65 to 231. Isaac and Bond (1963) found standing crops in pounds/acre to range from 80 to 736 and average 281 in 10 Oregon farm ponds. Standing crops of fish in 22 Kentucky farm ponds ranged from 73 to 770 and averaged 385 pounds/acre (Turner, 1960). In a study of 87 ponds in Alabama in which the standing crop was determined by draining, Swingle (1950) found a mean of 351 pounds/acre and a range from 18 to 1080.

Low standing crops of fishes in the present study may be partially explained by the following: (1) Standing crop estimates were made when the population was at an annual minimum; (2) Young-of-year fishes were not included in these estimates; (3) Under field conditions population estimates based on grouping the records for size classes were underestimates of the population by 10 to 20% (Cooper and Lagler, 1956); (4) The tendency of underestimation, owing to the recapture of marked individuals in proportions greater than their true abundance in the population, was the major source of errors of estimations of standing crops of fish by employing seines in 1-acre ponds (Buck and Thoits, 1965).

Production

The various factors regulating fish production are important to fisheries management, but are only partially known largely because of the lack of basic research upon these problems (Swingle, 1961). The Schnabel method estimates the population size at some time between the start and the end of marking. Thus, population estimates for the ponds in the present study would be at the time when the population numbers (N_1) would be near an annual minimum (Table XV), since there was a full year of mortality and no young-of-year fishes were included. The population size at the time when the population numbers approach a maximum for the year (N_0), can be obtained by the following equation:

$$N_0 = N_1/s$$

where s is the annual survival rate (Table XIV).

The mean weight ($\bar{w}_1$) (Table IX) corresponding to population size N_1 can be converted to $\bar{w}_0$, the mean weight of that species at the time when the population size was N_0, by the following equation:

$$\bar{w}_0 = \bar{w}_1/e^{\bar{\bar{g}}}$$

where $\bar{\bar{g}}$ is the average annual instantaneous mean growth rate (Table XIII) and e is the base of the natural logarithm. The stock weight of a species at time 0 (W_0), corresponding to time when the population size is N_0 can be obtained by the following equation:

$$W_0 = N_0 w_0.$$

Average stock weight during the year can be found by the equation:

$$\bar{W} = W_0(e^{\bar{\bar{g}} - i} - 1)/(\bar{\bar{g}} - i)$$

where i is the total instantaneous mortality rate (Table XIV) (Ricker, 1958). The mean number of fish in a species during the year, $\bar{N}$, can be calculated as follows:

$$\bar{N} = N_0(1 - e^{-i})/i$$

(Ricker, 1958). The mean bulk of a species, $\bar{W}$, or the average number of a species, $\bar{N}$, can be multiplied by any instantaneous rate or combination of rates, to show the mass or number of fish involved in the type of estimate desired (Ricker, 1958). The following computations were made (Table XVI):

$i\bar{W}$ = total mortality by weight, or in this case where there was an insignificant amount of fishing in the ponds it would also be the weight of fish which die due to natural mortality;

$\bar{\bar{g}}\bar{W}$ = net production, or total growth in weight of fish during the year, including growth in the part of the population which dies before the year ends;

$(\bar{\bar{g}} - i)\bar{W}$ = net change in weight of a species during the year (a

TABLE XVI

YEARLY PRODUCTION VALUES IN NUMBERS AND POUNDS/SURFACE ACRE

Pond	Spp.	N_0*	w_0	W_0	$\bar{W}$	Net Production	Weight of Fish That Die Due to Nat. Mort.	Net Change in Stock Weight	$\bar{N}$	No. Deaths Due to Nat. Mort.
L M	G S	5413	0.023	122.99	104.90	63.01	97.31	-34.30	3527	3272
	B B	485	0.063	30.39	46.99	41.72	3.38	38.35	468	34
Total				153.38		104.73	100.69	4.05		3306
B M	W C	2889	0.024	68.30	85.05	45.08	9.03	36.05	2741	291
	G S	13	0.026	0.32	0.36	0.20	0.13	0.07	11	4
	L M B	283	0.017	4.81	5.04	6.40	5.94	0.47	166	196
	O S	396	0.006	2.55	2.59	1.40	1.33	0.07	310	159
	B G	263	0.031	8.12	7.82	3.91	4.51	- 0.60	200	115
	R E	232	0.037	8.62	6.45	1.95	5.88	- 3.94	152	139
	C C	13	0.089	1.14	0.92	0.67	1.08	- 0.40	8	9
	Au S	16	0.024	0.39	0.39	0.13	0.12	0.01	14	4
Total				92.25		59.74	28.02	31.73		917
L C	G S	1267	0.034	43.06	53.48	40.48	18.06	22.42	1075	363
B C	G S	692	0.025	20.94	26.67	29.56	17.13	12.42	511	328
	L M B	208	0.095	19.74	15.41	9.75	17.72	- 7.96	124	142
	B B	7	0.532	3.51	3.31	2.22	2.61	- 0.39	5	4
Total				44.19		41.53	37.46	4.07		474

*Refer to text for discussion of symbols.

negative value indicates a decrease and a positive value indicates an increase);

$i\bar{N}$ = total number of deaths during the year, or in this case, the total number of deaths due to natural mortality, since there was no fishing mortality.

Since production rates were not computed for infrequently collected species and young-of-year fish, net production for each pond is a minimum value. Net production in pounds per surface acre at normal water level per year was 105 in Little Muddy Pond, 60 in Big Muddy Pond, 42 in Big Clear Pond, and 40 in Little Clear Pond (Table XVI). Net production in pounds per surface acre per year for green sunfish was 63 in Little Muddy Pond, 40 in Little Clear Pond, 30 in Big Clear Pond and 0.2 in Big Muddy Pond. Net production of black bullheads was greater in Little Muddy Pond, 42, than in Big Clear Pond, 2, partially because of a few large bullheads in Big Clear Pond and several small bullheads in Little Muddy Pond. In a study of hatchery ponds, Buck (1956) found a greater production of channel catfish in turbid than in clear ponds. The net production of largemouth bass was similar in Big Clear Pond and Big Muddy Pond (Table XVI).

Negative net changes in stock weight were found for bluegill, redear sunfish, and channel catfish in Big Muddy Pond; for largemouth bass and black bullheads in Big Clear Pond; and for green sunfish in Little Muddy Pond. All other species in all ponds showed a positive net change in stock weight during the year. The small positive total net change in stock weight for all four ponds was attributed mainly to a single species in each pond. In ponds where the fish populations have been established for several years, only small changes in the total stock weight of the pond would be expected during the year.

Production values are estimates of flesh production during 1 year. Standing crop values are estimates of accumulation of flesh over several years and are usually thought to exceed production values. However, in almost all species in all ponds in the present study, the net production/year was almost the same as the stock weight at the beginning of the year (Table XVI). Thus, the ponds produced almost as much fish flesh in a year as was present at the start of the year. The weight of fish that died due to natural mortality in most species was only slightly less than the stock weight at the beginning of the year (Table XVI). Since net production and weight of fishes dying due to natural mortality were similar, there would be little change in stock weight during the year.

Swingle Population Values

Production varies widely not only because of differences in fertility of various waters, but also because of varied coactions between and within species of fishes. The coactions are directly or indirectly the results of the predator-prey relationships between the piscivorous species and the forage species.

In the present paper, reference to the relationships between balanced and unbalanced fish populations, follows that outlined by Swingle (1950). The piscivorous fishes, forage fishes and the minimum harvestable sizes of the species are shown in Table XVII. The classifications in Table XVII are based upon values given in Swingle and

Swingle (1965). The following Swingle populations values, C (weight in pounds of piscivorous fish/acre), F (weight in pounds of forage fish/acre), F/C ratio, E (% of total weight of fishes in a pond composed of a certain species), R (% of total number of fishes in a pond composed of a certain species), A_t (% of total weight of fishes in a pond composed of fish of harvestable size) and the weight of harvestable fish in pounds/acre is given in Table XVIII.

TABLE XVII

INDEX TO SPECIES USED IN CALCULATION OF SWINGLE POPULATION VALUES
(Taken from Swingle and Swingle, 1965)

Species	Inch-Groups in "C" Class	Inch-Groups in "F" Class	Minimum Harvestable Inch-Group
W C	9+	0-8	9
B C	9+	0-8	9
L M B	All sizes		10
C C	16+	0-15	10
B B		All sizes	9
Au S		All sizes	7
M F		All sizes	
B G		All sizes	6
G S		All sizes	6
L E		All sizes	6
O S		All sizes	6
R E		All sizes	6

TABLE XVIII

SWINGLE POPULATION VALUES

Pond	Species	C Values	F Values	F/C Ratio	E Value	R Value	Harvestable Fish in Lbs/Surface Acre	A_t Value
L M	L E		4.73		3	3	t*	
	B B		68.74		40	17	t	
	G S		88.69		51	80	1.83	
	W C	7.63			4	t	7.63	
	C C		2.95		2	t	2.95	
Total		7.63	165.11	21.64			12.41	7
B M	W C	1.88	99.14		64	64	1.88	
	O S		2.62		2	6	t	
	B B		31.07		19	12	3.72	
	M F		0.004		t	t	t	
	G S		0.39		t	4	t	
	L M B	5.27			3	2	1.83	
	L E		6.63		4	5	t	
	R E		4.68		3	2	0.50	
	B G		7.53		5	4	t	
	R S		0.004		t	t	t	
	C C	0.31	0.45		t	t	0.42	
	Au S		0.39		t	t	t	
Total		7.46	152.91	20.50			8.35	5
L C	B B		80.20		44	7	80.20	
	L M B	42.19			21	23	23.04	
	G S		65.47		36	70	33.80	
	B C		0.04		t	t	t	
Total		42.19	145.71	3.45			137.04	73
B C	W C	5.08	0.08		9	1	5.08	
	L M B	11.77			4	11	18.75	
	L E		11.76		21	27	2.25	
	G S		33.36		59	60	18.75	
	C C	1.57			3	t	1.57	
	B B		2.92		5	t	2.91	
Total		18.42	48.12	2.61			49.31	74

*A "t" stands for less than 0.005 pounds/acre or less than one per cent.

Swingle populations values in the present study were computed by first estimating from the total catch of each species in each pond the proportion and the average weight above and below the minimum harvestable size (Table XVII) and the proportion and the average weight above and below the length at which a forage fish becomes a piscivorous fish (Table XVII). Second, these proportions were multiplied by the number of fish/surface acre (Table XV) of each species in each pond. This gave the number of harvestable and non-harvestable fish/acre in each species and the number of piscivorous or forage fish/acre in each species. Third, the number of harvestable and non-harvestable or piscivorous and forage fish/acre was then multiplied by the average weight above and below the minimum harvestable size. This gave the weight of harvestable and non-harvestable fish/acre or the weight of piscivorous and forage fish/acre. The population values given in Table XVIII can be calculated directly from the values obtained by the above methods.

The range of F/C ratios in balanced populations is from 1.4 to 10.0 with the most desirable range between 3.0 and 6.0 (Swingle, 1950). Ponds with F/C ratios between 1.4 and 2.0 are usually caused by overcrowded "C" species, while ratios greater than 10.0 are unbalanced because of low numbers of piscivorous fish and/or because of stunting of the fishes. Little Muddy Pond had a F/C ratio of 21.64 and Big Muddy Pond had a ratio of 20.50 and are unbalanced according to Swingle's criteria. Little Clear Pond had a ratio of 3.45 and Big Clear Pond had a ratio of 2.61 and were considered balanced (Table XVIII). Little Clear Pond was in the most desirable range of balanced ponds, while Big Clear Pond seems to be overcrowded with C fish. This overcrowding of C fish in Big Clear Pond may account for the low standing crop in this pond. Since piscivorous fish are higher in the food chain than forage fish, the ponds would not support as large a population of piscivorous as forage fish.

Swingle (1950) states that the range of A_t values in balanced populations is from 33 to 90 with the most desirable range between 60 and 85, while the range is 0 to 40 in unbalanced populations. He also states that the A_t value is the most useful indicator of balance and is a measure of the efficiency of a population in production of harvestable fish. Little Muddy Pond had an A_t value of 7 and Big Muddy Pond had an A_t value of 5 and were unbalanced according to this criterion. Little Clear Pond had an A_t value of 73 and Big Clear Pond had an A_t value of 74 and were considered balanced ponds (Table XVIII). The weight of fish in the clear ponds was composed mostly of harvestable-size fish, while the turbid ponds were composed almost entirely of non-harvestable fish (Table XVIII). The two balanced ponds had an average standing crop of 127 pounds/acre and the two unbalanced ponds had an average standing crop of 168. Turner (1960) found an average standing crop of 282 pounds/acre, ranging from 73 to 670 in balanced Kentucky ponds, while the average in 13 unbalanced ponds was 456 and ranged from 157 to 770. Swingle (1950) found an average standing crop of 236 pounds/acre in 55 balanced ponds in Alabama, and a mean of 328 in 34 unbalanced ponds.

Since each species within a pond is to some extent a competitor with the others, the percentages of total weight of the populations due to each species (E values) should be a measure of its relative survival efficiency under given environmental conditions (Swingle, 1950). Swingle and Swingle (1965) developed an additional relationship, R, which is similar to the E but based on numbers and not weight. Green sunfish had the largest E and R values in Little Muddy Pond (E = 51, R = 80) and Big Clear Pond (E = 59, R = 60), while white crappie had the largest E value (64) and R value (64) in Big Muddy Pond. Black bullhead had the largest E value (44) and green sunfish had the largest R value (70) in Little Clear Pond (Table XVIII). In a study of 42 Oklahoma ponds, Jenkins (1958) reported E values of 43 for black bullhead and 39 for bluegill. Turner (1960) found bluegills tended to be most abundant in all ponds in which they occurred in Kentucky and had average E values of 75 in the balanced populations and 87 in the unbalanced populations.

Species Diversity

Diversity indices express the distribution of individuals into species and permit summarization of large amounts of information about numbers and kinds of organisms (Patten, 1962). Species diversity was calculated for fish in each pond to see if there was a direct relationship between it and other biological or physical factors.

Estimates of diversity/individual ($\bar{H}$) were obtained with the following equation (Patten, 1962):

$$\bar{H} = \sum_{i=1}^{m} (n_i/N) \log_2 (n_i/N)$$

where (N) is the total number of organisms, (n_i) number of individuals/species, and (m) the number of species in a unit area (Table XIX).

Another index of diversity, d, derived from the linear relationship between the number of species and the logarithm of total individuals (Margalef, 1951) was calculated as follows:

$$d = m - 1/\ln N.$$

TABLE XIX

FISH SPECIES DIVERSITY[a]

Pond	$\bar{H}$	d
L M	0.52	0.51
B M	2.17	2.09
L C	1.02	1.00
B C	1.20	1.09

[a]Based on total catch from each pond with numbers of individuals adjusted to per acre foot

Both indices of species diversity $\bar{H}$ and d were similar to each other for each pond (Table XIX). Little Muddy Pond had the lowest species diversity ($\bar{H}$ = 0.52, d = 0.51) of all ponds, because there were few species present and most of the individuals in the pond belonged to a single species. Big Muddy Pond had the highest species diversity ($\bar{H}$ = 2.17, d = 2.09) because of the large number of species present. Species diversity in the clear ponds (LC, $\bar{H}$ = 1.02, d = 1.00; BC, $\bar{H}$ = 1.20, d = 1.09) was very similar.

Correlation coefficients between species diversity ($\bar{H}$) and surface area at normal water level and at spillway level were both 0.87. The coefficient between $\bar{H}$ and volume of the ponds in acre feet at normal water level was 0.74, while it was 0.94 between $\bar{H}$ and drainage area.

There was a positive correlation between fish species diversity ($\bar{H}$) and mean phytoplankton species diversity ($\bar{H}$) (r = 0.57), and between fish species diversity ($\bar{H}$) and mean zooplankton species diversity ($\bar{H}$) (r = 0.52). Mean phytoplankton and zooplankton species diversity values were obtained from Knudson (1967).

Interrelationships of Standing Crop and Net Production of Fish With Environmental Factors

A single index to the basic fish-producing capacity of a body of water does not exist. When sufficient information on the physicochemical and biological factors that affect fish production becomes available, a multiple factor index to fish production may be developed.

Correlation coefficients for standing crop and net production of fish/acre and environmental factors are given in Table XX.

Negative correlations were found between transmission of light and standing crop (r = -0.41) and net production (r = -0.94) of fish/acre (Table XX). Since an increase in transmission of light would correspond to a decrease in turbidity, these results are contradictory to those of Schneberger and Jewell (1928) who reported a negative correlation between turbidity and fish production (r = -0.98) and to Buck (1956) who found a negative correlation between yield of fish and turbidity (r = -0.762). Murphy (1962) stated that mixing depth and turbidity negatively affect the productivity of an aquatic environment through the control they exert on the effective energy available for photosynthesis. This contradiction can be accounted for partially because the clear ponds contained a smaller percentage of forage fishes than the turbid ponds and should not support as large a standing crop of

TABLE XX

CORRELATION COEFFICIENTS OF STANDING CROP AND NET PRODUCTION OF FISH PER ACRE WITH ENVIRONMENTAL FACTORS

Variables for Which S C and P are compared[a]	r for S C vs Variable in Column 1[b]	r for P vs Variable in Column 1
Total dissolved solids	-0.93	-0.69
Dissolved organic solids	-0.34	-1.00
Mean depth	-0.71	-0.89
Surface area at normal water level	-0.54	-0.43
Volume at normal water level	-0.73	-0.52
Drainage area/spillway volume	0.77	0.65
Number spp. of fish	-0.02	-0.04
A_t value	-0.44	-0.78
C value	0.19	-0.64
F value	0.96	0.57
F/C ratio	0.46	0.82
H for fish	-0.08	-0.44
H for phytoplankton	-0.36	-0.99
H for zooplankton	-0.63	-0.94
Gross Primary Productivity	0.18	0.95
Plankton biomass	0.80	0.59
Total nitrogen	-0.66	0.29
Total phosphorus	0.07	0.57
Calcium	0.83	0.18
Magnesium	-0.70	-0.87
Sulphate	0.85	0.80
Nitrate	-0.24	0.70
Orthophosphate	-0.98	-0.45
Total iron	0.30	0.96
Chloride	-0.97	-0.49
Sodium	-0.89	-0.65
Mg/Ca ratio	-0.94	-0.67
Mean annual conductivity	-0.86	-0.79
Mean annual pH	-0.71	-0.80
Mean annual carbonate	-0.87	-0.54
Mean annual bicarbonate	-0.83	-0.75
Per cent transmission	-0.41	-0.94

[a]S C is standing crop/surface acre and P is net production/surface acre.

[b]r is correlation coefficient.

fish as the turbid ponds. Also, the clear ponds had a greater percentage of harvestable piscivorous fish which would contribute to a lower standing crop, since a larger portion of the total standing crop was on a higher trophic level and larger fish usually grow slower than smaller ones.

Negative correlations were found between standing crop of fish/acre and surface area of ponds (r = -0.54) and volume of ponds (r = -0.73), and between net production of fish/acre and surface area of ponds (r = -0.52). Rounsefell (1946), Carlander (1955) and Hayes and Anthony (1964) also found a negative relationship between standing crop of fish and the size of the body of water. Rounsefell (1946) suggested that

> ... the yield per acre of lake is probably correlated with the relative area of fertile shallow water, which is generally much less in proportion to the total area in the larger lakes than in smaller ones, as indicated by the difference in the length of shoreline.

Positive correlations were found between the ratio of drainage area to spillway volume and standing crop (r = 0.77) and net production (r = 0.65) of fish/acre. A larger ratio of drainage area to spillway volume tended to produce more turbid ponds. Since positive correlation was found between standing crop and turbidity, the above relation could be expected.

Negative correlations were found between mean depth of ponds and standing crop (r = -0.71) and net production (r = -0.89) of fish/acre. Carlander (1955), Hayes and Anthony (1964), Ryder (1965) and Jenkins (in press) also found a negative correlation between standing crop of fish and depth of water.

Negative correlations were found between total dissolved solids and standing crop (r = -0.93) and net production (r = -0.69) of fish/acre. Northcote and Larkin (1956) found a positive relationship between net haul catches and total dissolved solids in 100 British Columbia lakes. Isaac and Bond (1963) found no clearly defined relation between standing crop and total dissolved solids in Oregon ponds. Jenkins (in press) found a positive correlation between fish standing crop and total dissolved solids for large reservoirs.

Negative correlations were found between standing crop of fish/acre and mean annual bicarbonate (r = -0.83) and carbonate (r = -0.87) and between net production of fish/acre and mean annual bicarbonate (r = -0.75) and carbonate (r = -0.54). Moyle (1949) identified total alkalinity and total phosphorus as the most valuable indices of fish productivity in Minnesota lakes. Jenkins (1958) found positive correlations between standing crop and methyl orange alkalinity in a study of 42 Oklahoma farm ponds. Turner (1960) found positive correlations between standing crops of 22 Kentucky ponds and total alkalinity, potassium and phosphorus present in the watershed soils. In this study, both mean annual carbonate and bicarbonate were higher in the clear than in the turbid ponds, although mean annual bicarbonate in Little Clear Pond was lower than in Big Muddy Pond. The contrast between these findings and those of other authors may be associated with factors discussed above under light transmission.

No correlation was found between standing crop or net production of fish/acre and number of species present (Table XX). Carlander (1955) and Jenkins (1958) found a positive correlation between standing crop of fish/acre and the number of fish species.

A positive correlation (r = 0.95) was found between net production of fish/acre and gross primary productivity (Table XX). McConnell (1963), in the study of a small desert impoundment, stated that it was impossible to ascribe with certainty any single year of fish biomass increase to a single year of primary production. Although Smith and Swingle (1939) did not work on primary productivity, they found a direct relationship between the total organic matter in the water and the production of bluegills in Alabama experimental ponds.

Negative correlations were found between A_t values and standing crop (r = -0.44) and net production (r = -0.78) of fish/acre. With an increase in the per cent of harvestable piscivorous fish, the potential standing crop of a pond would be lower since a larger portion of the total standing crop of fishes would be on a higher trophic level and larger fish usually grow slower than smaller ones.

Positive correlations were found between F values and standing crop (r = 0.96) and net production (r = 0.57) of fish/acre. Since forage fishes are on a lower trophic level, ponds with a high F value should have a larger standing crop of fish than ponds with a lower F value.

Small negative correlations were found between species diversity ($\bar{H}$) of fish and standing crop (r = -0.08) and net production (r = -0.44) of fish/acre.

Stroud (1967) stated that the dissolved oxygen level should not be below 5 ppm for warm-water fish. The dissolved oxygen level in all four ponds was above 5 ppm during the study, except on three occasions in Little Clear Pond when the dissolved oxygen level was 3.9 ppm on August 4, 1965, 4.8 ppm on August 23, 1965, and 3.8 ppm on September 11, 1965, and one occasion in Big Clear Pond with 3.2 ppm on August 31, 1965. Thus, oxygen was probably not a limiting factor in the ponds. Stroud also stated that pH values should be in the range from 5 to 9.5 and for good game fish production they should be in the range from 6.5 to 8.5. The turbid ponds in this study were in the range of 6.5 to 8.5, but the clear ponds exceeded 8.5 during part of the year. Big Clear Pond had a pH of 9.6 for several weeks during the summer and this may have contributed to the low standing crop of fish.

CHAPTER VI

SUMMARY

A study was made of the influence of physicochemical and biological factors on fish population parameters in two turbid and two clear ponds. One turbid and one clear pond were each approximately 5 acres in surface area, while the other two ponds were each about 1 acre. The ponds are referred to as Little Muddy Pond (LM), Big Muddy Pond (BM), Little Clear Pond (LC) and Big Clear Pond (BC). Five fish species were captured from Little Muddy Pond, 12 from Big Muddy Pond, four from Little Clear Pond and six from Big Clear Pond.

Mean annual growth rate of green sunfish was greater in clear than in turbid ponds, while the mean annual growth rate of black bullheads was greater in turbid than in clear ponds.

The annual survival rates of green sunfish were 0.3955 in Little Muddy Pond, 0.7000 in Big Muddy Pond, 0.7188 in Little Clear Pond and 0.5260 in Big Clear Pond. Largemouth bass had a higher annual survival rate in clear ponds (LC = 0.7134, BC = 0.3168) than in Big Muddy Pond, 0.3077. Annual survival rate of black bullheads was higher in Little Muddy Pond, 0.9307, than in Big Clear Pond, 0.4545. The mean annual survival rate of all species in all ponds was 0.5712.

Standing crop estimates in pounds/acre at normal water level were 173 in Little Muddy Pond, 164 in Big Muddy Pond, 188 in Little Clear Pond, 67 in Big Clear Pond and a mean of 148 for all four ponds.

Net production in pounds per surface acre per year was 105 in Little Muddy Pond, 60 in Big Muddy Pond, 42 in Big Clear Pond and 40 in Little Clear Pond. The small positive total net change in stock weight in each pond was attributed mainly to a single species.

According to Swingle's F/C ratios and A_t values, the clear ponds were balanced and the turbid ponds were unbalanced. The F/C ratios were 21.64 in Little Muddy Pond, 20.50 in Big Muddy Pond, 3.45 in Little Clear Pond and 2.61 in Big Clear Pond, while the A_t values were 7 in Little Muddy Pond, 5 in Big Muddy Pond, 73 in Little Clear Pond and 74 in Big Clear Pond. The two balanced clear ponds had an average standing crop of 127 pounds/acre and the two unbalanced turbid ponds had an average standing crop of 168. Green sunfish had the largest E and R values in Little Muddy Pond (E = 51, R = 80) and in Big Clear Pond (E = 59, R = 60), and white crappie had the largest E value, 64, and R value, 64, in Big Muddy Pond. Black bullheads had the largest E value, 44, and green sunfish had the largest R value, 70, in Little Clear Pond.

Species diversity of fish, $\bar{H}$, in the ponds was 0.52 in Little Muddy Pond, 2.17 in Big Muddy Pond, 1.02 in Little Clear Pond and 1.20 in Big Clear Pond.

Correlation coefficients were determined for standing crop and net production of fish/acre with 32 environmental factors.

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