323
65

EFFECTS OF TURBIDITY ON FISH AND FISHING

By

D. HOMER BUCK

A two-year study sponsored by

OUTBOARD BOATING CLUB OF AMERICA
OKLAHOMA GAME AND FISH DEPARTMENT
SPORT FISHING INSTITUTE

Cooperating agencies

OKLAHOMA A. AND M. COLLEGE
UNIVERSITY OF OKLAHOMA
CITY OF TULSA WATER DEPARTMENT
U.S. ARMY, CORPS OF ENGINEERS

OKLAHOMA FISHERIES RESEARCH LABORATORY
REPORT NUMBER 56
MARCH, 1956
NORMAN, OKLAHOMA

THE OKLAHOMA FISHERIES RESEARCH LABORATORY

Robert M. Jenkins, Director

plankton methods pp 4-5
effects on fish reproduction pp 20-21
effects of silted vs unsilted pond bottoms
on fish pp 22-23
plankton production pp 24-25
summary of overall effects of turbidity pp 56-57

SUPPORTING AGENCIES

The Oklahoma Game and Fish Department

and

The University of Oklahoma Biological Survey

ADVISORY COMMITTEE

George L. Cross, President, University of Oklahoma

John E. King, Chief, Fisheries Division, Oklahoma Game and Fish Department

Carl D. Riggs, Director, University of Oklahoma Biological Survey

Laurence H. Snyder, Director of Organized Research, University of Oklahoma

Mutt Standefer, Assistant Director, Oklahoma Game and Fish Department

Dave Ware, Director, Oklahoma Game and Fish Department

Table of Contents

	Page
Introduction.....	1
Methods and Procedures.....	3
Farm Pond Studies.....	6
Selection and description.....	6
Stocking.....	8
Sampling.....	8
Total yield.....	10
Growth of fishes.....	14
Spawning success.....	19
Plankton production.....	25
Hatchery Pond Experiments.....	25
Methods and procedures.....	27
Findings.....	32
Reservoir Studies.....	39
Largemouth bass.....	41
Crappies.....	43
Catfishes.....	46
Population estimates.....	48
Plankton production.....	52
Fishing success.....	52
Discussion.....	54
Summary.....	56
Bibliography.....	59

A summary of this study was presented by Dr. Buck at the 21st North American Wildlife Conference in New Orleans, Louisiana, March 5, 1956.

Acknowledgements

This was a cooperative project of the Outboard Boating Club of America, the Oklahoma Game and Fish Department, and the Sport Fishing Institute. The need for such a study was first expressed by the Sport Fishing Institute. Initial impetus was provided by a grant of \$10,000.00 from the Outboard Boating Club and its sponsoring boat and motor industries. Acting as intermediary, the Sport Fishing Institute gained the cooperation of the Oklahoma Game and Fish Department, which agreed to contribute additional financial support and to supervise the investigation. The author was placed in the employ of the Fisheries Division, Oklahoma Game and Fish Department, with the Sport Fishing Institute continuing in an advisory capacity.

For their generous cooperation, particular thanks are due to E. M. Leonard and Gordon E. Hall, both former Directors, and to John E. King, present Director of the Fisheries Division, Oklahoma Game and Fish Department; to Robert M. Jenkins, Director, and associates Joe Finnell and Ronald Elkin of the Oklahoma Fisheries Research Laboratory; to H. C. Clemens and Carl D. Riggs of the University of Oklahoma; to Robert E. Hunter and W. H. Thompson, of the Corps of Engineers, Tulsa District; to J. W. Costilow and Sam W. Jackson, Jr., of the City of Tulsa, with special thanks to the latter for use of unpublished data from Upper Spavinaw Reservoir; to O. E. Orr for use of unpublished Heyburn Reservoir data; to Glenn Jones, A. W. Hill and Farrell Copelin for assistance in the field. Finally, special recognition is due Frank J. Claffey for use of unpublished plankton and light penetration data, and to W. H. Irwin, of Oklahoma A. and M. College, for his many highly valued contributions to the study.

EFFECTS OF TURBIDITY ON FISH AND FISHING

D. Homer Buck

INTRODUCTION

The role of soil erosion in land management has been well documented. Its influence on the productivity of our inland waters has received relatively little attention. While it is widely recognized that turbidities caused by erosion silt are generally harmful to the aquatic community, little quantitative data exists as to its effects on fish growth and reproduction, basic food production, and fishing success. The purpose of this investigation has been to categorize and measure some of the influences of erosion silt on fish and fishing in ponds and reservoirs of Oklahoma.

Various phases of the turbidity problem have received previous attention in Oklahoma. Irwin (1945-1948), and Irwin and Stevenson (1951) described the nature and cause of turbidities in central Oklahoma and presented methods for clarification of turbid waters. Wallen (1951) studied the direct effects of clay turbidities on fishes in terms of lethal concentrations and concluded that the direct effect of clay turbidity is not a lethal factor at concentrations found in Nature. In a study of the effects of turbidity on bottom fauna, Hambric (1953) found that clear ponds produced greater numbers of bottom organisms but that volumes in turbid ponds were often greater due to an abundance of the large naiads of a species of mayfly, Hexagenia limbata. Moore (1944, 1951) has studied the rather remarkable adaptations of certain minnows for survival in muddy waters of the

Great Plains Region. Aldrich (1949), Hall (1952), Jenkins and Hall (1953), Hall, Jenkins and Finnell (1954), and Finnell and Jenkins (1954) have emphasized the general unsuitability of turbid waters for efficient fish production, and in their most recent writings, Jenkins, Hall, Finnell, et al, have called special attention to the retarding influence of turbid waters on growth of largemouth bass, white and black crappies, and channel catfish.

Elsewhere the turbidity problem has been considered from a variety of viewpoints. A few investigators have concluded that certain fishes spawn more successfully in turbid waters and that turbidity affords protection and, in some instances, food to young of fishes (Ward, 1938; Doan, 1941, 1942; Lagler and Ricker, 1942; Chandler, 1942; Van Oosten, 1948). Others have noted that high turbidities cause loss of eggs or nests, and severely limit or eliminate spawning activities in some areas (Ellis, 1937; Shapavalov, 1937; Ward, 1938; Smith, 1940; Sumner and Smith, 1940; Langlois, 1941; Elder and Lewis, 1955). In Illinois, Bennett, Thompson and Parr (1940) noted that fishing success depended upon transparency of the water, and that as turbidity decreased, rate of catch increased. Bennett (1943) further observed that successful bass populations were associated with clear waters, and that less desirable species tended to predominate in turbid waters. Swingle (personal communication) has observed in a large number of Alabama ponds that heavy silt loads during the spawning season prevent the successful reproduction of largemouth bass. Burress (personal communication) has observed in Missouri that largemouth bass spawn more successfully and make more rapid growths in clear than in muddy ponds. Several authors have observed that turbidity effects a loss in fish pro-

duction but have given no turbidity readings (Smith, 1940; Chandler, 1942a; Swingle, 1949; Fessler, 1950; and numerous others). There is, in fact, a notable paucity of data relating fish growth and reproduction to measured turbidities. The only known record was made in an early work by Schneberger and Jewell (1928) in studying factors affecting pond fish production in Kansas. They observed that, other things being equal, the fish production in ponds was directly related to clearness of the water for turbidities above 100 ppm, but that other factors become more influential at lesser turbidities.

Various writers have noted the effects of turbidity and siltation on lesser aquatic organisms. Some assert that turbidity and associated sedimentation often limit the production of algae, as well as higher aquatic plants (Chandler, 1940, 1942a, 1944; Meyer and Heritage, 1941; Langlois, 1941, 1945; Chandler and Weeks, 1945; Moen, 1947). Others credit the same processes with eliminating many bottom organisms important as fish food (Ellis, 1936, 1937, 1944; Sumner and Smith, 1940; Smith, 1940; Munns, 1948; Hambric, 1953). Perhaps the widest attention has been given to the effects of turbidity in excluding light from the aquatic environment and the critical limitations thereby imposed on aquatic organisms (Ellis, 1931, 1936, 1937, 1944; Welch, 1935; Chandler, 1940, 1942a, 1942b, 1944; Doan, 1942; Shaw and Maga, 1943; Meyer, Bell Thompson and Clay, 1943; Chandler and Weeks, 1945; Irwin, 1945, 1948; Moen, 1947; Munns, 1948; Aldrich, 1949; Hall, 1952; Berner, 1951; Hambric, 1953; Claffey, 1955).

METHODS AND PROCEDURES

The present problem was studied in farm ponds, in partially controlled

hatchery ponds, and in large reservoirs. This was a two-year project, initiated in January, 1954, and terminated December 31, 1955. The spring and fall months were devoted primarily to the farm ponds the first year and to both the farm and hatchery ponds the second year. Both summers were largely devoted to the reservoir studies.

A selected series of 39 farm ponds was rotenoned and restocked in the spring of 1954. Turbidity and plankton samples were taken throughout the next two growing seasons. The fish populations were sampled at the end of each growing season. These experiments provided information on growth, reproduction, and total production of fish, and on production of basic fish foods in waters having a wide range of natural soil turbidities.

The hatchery pond experiments were initiated in the spring of 1955. This project involved artificially created turbidities in small, controlled ponds from which the fish populations could be recovered by draining. Fourteen ponds were used.* Six were kept turbid by the periodic addition of a native clay and small amounts of sodium silicate solution (common Water Glass), which served as a dispersing agent. A second six ponds were kept turbid by adult carp, and four ponds were left untreated as controls, although only the results from two proved usable. All ponds were stocked with equal numbers of largemouth bass, bluegills and channel catfish.

The studies of the two large reservoirs, one muddy, the other clear, were made in order to measure some of the effects of turbidity on natural, uncontrolled populations in larger bodies of water. Points of comparison were fish growth and reproduction, relative abundance of important species,

*Originally 16 were used, but two control ponds were dropped because of contamination by trash fishes and because of their small size.

basic food production, and fishing success.

Turbidities were measured by the Jackson Turbidimeter which makes no determinations lower than 25 ppm. For the purpose of computing average turbidities for those ponds which ranged above and below the 25 ppm level, an arbitrary value of 15 ppm was substituted in the calculations for all readings of "less than 25 ppm."

Plankton referred to are net plankton collected with a Wisconsin type net made up with No. 25 mesh silk bolting cloth. Plankton counts were made by use of the Sedgwick-Rafter counting cell. Volumetric measurements were made by centrifuging the plankton concentrates from 30 liter samples at 3000 RPM for two minutes.

All fish lengths were recorded in inches and tenths and all weights in pounds and hundredths of pounds. All lengths used herein refer to total lengths.

Final population estimates in the farm ponds were computed from the percentage of marked fish recovered following treatment by rotenone. Fish were ordinarily marked one or two days previous to the rotenone treatment. The marking technique used was to remove a small section of the upper lobe of the caudal fin. Bass of all sizes were marked, but it was found impractical to mark sunfishes less than 3 inches in length. The smallest bass were mostly longer than 3 inches, but on one occasion bass as small as 1.9 inches were successfully marked and recovered. Numbers and weights of small, unmarked bluegill and redear were estimated by collecting all fish for as many days as they continued to appear (7 days in some instances) and multiplying the totals by three. The multiple of three was chosen on the basis of returns from a marking experiment made in one small pond and

on the basis of past observations of the author and associates. The totals thus derived are believed conservative. While they cannot be presented as completely accurate determinations, they are believed sufficiently reliable for comparative purposes.

FARM POND STUDIES

Selection and Description of Ponds

All ponds used were typical farm or ranch ponds, most of which were built for stock-watering purposes. Cooperation and interest of the land-owners, as well as size and other physical characteristics of the ponds were considerations in their selection. Clear ponds are rare in central Oklahoma, and the use of an airplane saved much time. Once a clear pond was located from the air it was relatively simple to match it with a muddy pond in the same watershed. Ideal situations were those in which two ponds were located in the same drainage, one immediately above the other. Such upper ponds served as settling basins and were almost invariably muddy, while the lower ponds were usually clear. Single ponds without settling basins were seldom clear except when located in well-grassed pastures having an efficient means of runoff control.

A total of 39 ponds were selected for study. Sixteen were located in Cleveland County, 23 in Payne County, approximately 70 miles north and slightly east of the Cleveland County area. Land use, soils, and substrates of the areas are very similar, both underlain by Permian red beds, with surface soils containing much colloidal clay. Sizes of ponds used and other physical characteristics are presented in Table 1.

Table 1. Turbidities in parts per million, transparencies in inches (Secchi Disc), size and depths of farm ponds used.

Pond no.	Name of pond	Turbidities ¹ Average range	Average transparencies ²	Size in acres	Depths in feet	
					Average	Maximum
1	Leach No. 1	-25 (-25to-25)	44.3	1.1	6.0	10.0
2	Petty	" (" to 65)	42.3	2.0	6.0	12.0
3	Osborne No. 3	" (" to 42)	41.2	1.0	5.0	7.0
4	Nelson	" (" to-25)	38.6	0.7	3.0	7.0
5	Village	" (" to 60)	37.0	1.9	5.0	10.5
6	Preston No. 1	" (" to 80)	31.2	1.3	5.0	11.0
7	Newsom No. 1	" (" to 60)	30.5	1.5	6.0	12.0
8	Berry No. 1	" (" to 138)	27.0	0.8	2.5	4.0
9	Newsom No. 2	" (" to 70)	25.6	1.9	5.0	10.0
10	Osborne No. 1	" (" to 105)	20.7	1.0	2.8	5.5
11	Miller No. 1	" (" to 60)	20.0	0.8	3.7	7.0
12	Fisher No. 1	" (" to 100)	14.0	2.0	3.0	6.0
13	Andrews No. 1	45 (-25to 90)		2.3	4.0	9.0
14	Schachle	46 (" to 90)		0.9	4.5	8.5
15	Law	50 (" to 120)		1.1	1.8	3.0
16	Berry No. 2	58 (" to 160)		0.9	2.0	4.5
17	Smith	64 (" to 190)		0.5	3.5	6.0
18	Leach No. 2	71 (" to 150)		0.4	2.0	4.0
19	Allred No. 3	76 (" to 280)		0.8	3.0	7.0
20	Ross	83 (37to 330)		1.0	3.0	6.0
21	Andrews No. 2	86 (29 to 163)		1.5	2.0	4.5
22	Glass	94 (28 to 250)		1.9	3.0	7.0
23	Fisher No. 2	99 (-25to 300)		0.9	3.0	6.0
24	Miller No. 2	100 (-25to 475)		0.8	3.8	6.8
25	Hansmeyer No. 1	107 (65 to 177)		0.4	1.7	3.0
26	Allred No. 4	122 (64 to 226)		1.1	3.0	7.0
27	Allred No. 1	132 (75 to 232)		0.5	3.5	7.0
28	Marler	148 (110to 280)		1.1	1.8	4.0
29	Preston No. 2	185 (73 to 350)		1.2	3.0	7.0
30	Metzger	203 (27 to 625)		1.8	2.5	5.0
31	Hansmeyer No. 2	239 (64 to 875)		0.9	2.0	3.5
32	Moroney	339 (90 to 1500)		1.1	2.2	4.5
33	Osborne No. 2	388 (62 to 800)		0.9	2.0	4.0

1 Represent readings through two years for all ponds except Nos. 1, 10, 15, 25 and 33, which were ~~not~~ used in 1955.

2 Represent averages through 1954 only.

Stocking the Farm Ponds

Ponds were rotenoned in March and April, 1954, to remove existing fish populations. The usual treatment was 1.5 ppm of Derris powder (5% rotenone), and later sampling indicated a high percentage of complete kills.

Fish for stocking the ponds were obtained from the State Fish Hatchery at Durant, Oklahoma. The Cleveland County ponds were stocked on May 12, 1954, using 100 largemouth bass and 100 redear sunfish each, per surface acre. The Payne County ponds were stocked on May 19 using the same ratio except that some ponds received bluegills instead of redear. Bass and redear were all one year old fish, the bluegills were slightly larger and contained both one and two-year-old individuals. The average weights of fish stocked in various ponds are shown in Table 4.

Sampling the Farm Pond Fish Populations.

The first sampling of the fish populations was made between September 6 and October 16, 1954. The purpose was to determine rates of growth and spawning success. This was accomplished chiefly by use of seines and electro-fishing gear, but one pond was rotenoned when other methods proved ineffective. Efforts were made to recover at least 10 per cent of the original number stocked. Fish were held at pondside in tanks with portable oxygen equipment until a sufficiently large sample was obtained, and the fish were then immobilized with urethane so that they could be accurately weighed and measured and returned to the water as rapidly as possible. The procedure proved very satisfactory, and left the populations intact for future study.

The fish were again left undisturbed until the following fall. In this final examination efforts were made to obtain complete population estimates

whenever possible. Fourteen ponds were rotenoned after portions of the population had been marked. Six additional ponds were sufficiently seinable to provide some usable population data, although no accurate estimates of the small (less than 3.0 inches in length) unmarked fish could be obtained in this way. Numbers of the larger marked fish were computed from the proportions of marked fish obtained by repeated seining efforts in the manner proposed by Schnabel (1938). The remaining 8 ponds could not be rotenoned because of lack of permission of the pondowners and could not be seined efficiently enough to allow a population estimate. In most cases, however, the seines and electric gear provided adequate samples for determination of growth rates and the occurrence or non-occurrence of reproduction.

Results for the two separate years are presented more or less concurrently. Usuable data were collected from 33 ponds the first year, and from 28 the second. Five of the original 39 ponds went dry, or nearly so; two became badly contaminated by trash fish; two were renovated by the owner; one was found to have been improperly stocked; and one had been rotenoned at the end of the first year. Most ponds had slightly higher turbidities during the second year due to a greater rainfall and larger runoff, but in only two ponds was the difference large. For most purposes the average turbidities assigned to the ponds represents a simple average of all readings taken over the two-year period of study. These included an average of 9 readings (8 for some ponds, 10 for others) taken at regular intervals from May to October in 1954, and 8 readings taken from March through August in 1955. For those ponds from which data were collected only in 1954, the turbidities assigned of course represent an average for only the single year.

FINDINGS FROM THE FARM PONDS

Relation of Turbidity to Total Yield

Turbidity was found to have a definite relation to total production of fishes. The clear ponds yielded not only a much greater weight of fishes but also greater numbers of large fishes. This presentation is limited to those ponds for which total population estimates were made at the end of the second growing season. Production figures for individual ponds are presented in Table 2 together with the weights and percentages of separate components of the populations. The correlation between yield in pounds of fish per acre and turbidity was -0.762 , which was significant at the $.01$ level. The regression of yield on turbidity was $P = 142.1 - 0.502A$, where P = pounds of fish per acre and A = average turbidity in parts per million.

By way of further analysis, the 12 ponds were separated into the following three classifications of turbidity: 1) clear ponds, with average turbidities of less than 25 ppm; 2) intermediate ponds, with a range of turbidities from 25 to 100 ppm; and 3) muddy ponds, with turbidities in excess of 100 ppm. It may be seen in Table 2, and graphically in Figure 1, that the average total weight of fishes in the clear ponds was 161.5 pounds per acre, as compared with 94 in the intermediate and only 29.3 in the muddy ponds. The differences were due to faster growths made in the clearer waters and to the vastly greater amounts of reproduction in the clear ponds, particularly by the bluegill and redear sunfish.

Estimates were also made of the numbers and weights of the different sizes of fish produced in the three categories of ponds. Table 3 shows that for bass of desirable length (10 inches or longer), the muddy ponds yielded

Table 2. Yields in pounds per acre and percentage composition (in parentheses) of fishes in 12 ponds for which total populations were estimated.

Pond no.	Average turbidity	Largemouth bass		Redear sunfish		Bluegill		Total Weights
		Adults ¹	Young ²	Adults ¹	Young ²	Adults ¹	Young ²	
4	-25	8.4 (4.2)	13.8 (6.8)			5.7 (2.8)	174.3 (86.2)	202
6	"	16.6 (14.7)	6.8 (6.0)			7.9 (7.0)	32.3 (72.3)	114
7	"	19.7 (10.7)	23.3 (12.7)	17.5 (9.5)	123.2 (67.1)			184
9	"	17.9 (12.2)	3.7 (2.5)	14.4 (9.8)	111.3 (75.5)			147
Averages for clear ponds		15.7 (10.5)	11.9 (7.0)	16.0 (9.7)	117.3 (71.3)	6.8 (4.9)	128.3 (79.3)	161.5
14	46	5.1 (6.5)	20.6 (26.4)	10.5 (13.5)	41.8 (53.6)			78
17	64	16.8 (14.3)	11.9 (10.1)	21.0 (17.9)	68.0 (57.7)			118
19	76	15.4 (12.9)	24.2 (20.3)	16.5 (13.9)	63.0 (52.9)			119
22	94	27.5 (45.5)	6.3 (10.4)	7.4 (12.2)	19.4 (32.0)			61
Averages for intermediate		16.2 (19.8)	15.8 (16.8)	13.9 (14.4)	48.1 (49.1)			94
26	122	6.0 (21.0)	4.6 (16.0)			10.7 (37.0)	7.5 (26.0)	29
27	132	14.1 (53.0)	0	11.8 (44.4)	0.7 (2.6)			27
29	185	18.4 (43.8)	0			14.5 (34.5)	9.1 (21.7)	42
32	339	5.0 (26.3)	0	14.0 (73.7)	0			19
Averages for muddy ponds		10.9 (36.0)	1.2 (4.0)	12.9 (59.1)	0.4 (1.3)	12.6 (35.8)	8.3 (23.9)	23.3

1 Represent survivors of original stock.

2 Includes reproduction for both years.

Figure 1. Average estimated total weights and compositions of fish populations in four clear, four intermediate and four muddy ponds at end of second growing season. Fish classed as adults indicate surviving original stock; fish classed as young indicate combined reproduction for both years. Bluegill and redear sunfish are combined as sunfish; four ponds containing bluegill, eight redear sunfish.

only a small fraction of the weight of desirable bass produced in the clear and intermediate ponds. The intermediate ponds yielded more bass over 10 inches (although their average length was less) than the clear ponds, which was believed due to the fact that a greater number of large bass were caught by anglers from the clear than from the intermediate ponds.* The small weight of desirable bass from the muddy ponds reflects the fact that few individuals in these ponds ever attained the 10-inch length, with most of the original stock still within the 6-10 inch length range. The greater weight of 6 to 10-inch bass in the clear than in the intermediate ponds is due largely to the faster growth made by young bass in the clear ponds. This production was more than balanced, however, by a greater yield of small bass (less than 6.0 inches) in the intermediate ponds so that total weights (all sizes combined) of bass were somewhat greater in intermediate ponds than in clear ponds. This is attributed to the varying rates of competition from the bluegills or redears since the weights of the companion sunfishes were more than twice as great in the clear than in the intermediate ponds. The extremely poor production of bass in the muddy ponds must be attributed directly to turbidity, since yields of all species were uniformly low from these ponds.

Comparisons of the weights of sunfishes also shows a notably smaller production in the muddy than in the clearer ponds. The most significant comparisons are between the fishes of the two smaller size ranges, since the populations of larger fishes were again influenced by angling pressure as well as by mortality and intraspecific competition (this will be discussed more fully in the following section). The greater weight of bluegills

* Fishing was discouraged, but it was impossible to control. The fishing occurred during the second summer, and it is known that rather large numbers of adult bass were caught from all four clear ponds and two intermediate ponds, and that bluegills were caught from at least two of the clear ponds cited above.

than redears in the 3 to 6 inch range (Table 3) is believed to have no significance beyond the fact that the bluegills were larger and older than the redears when stocked and therefore capable of greater initial spawning activity in 1954.

Relation of Turbidity to Growth of Fishes

Growth of bass was most notably affected by the turbid conditions. Effects on growth of redears and bluegills were consistent, but less pronounced, and intraspecific competition in some instances appeared more influential on growth of sunfishes than turbidity.

Growth data are presented from 33 ponds for the first year, and from 28 for the second. Unless otherwise stated, the growths presented refer to growth increments made by individuals of the original plant of fishes and not to that of their progeny. The data are presented on the basis of average turbidities, employing the same categories of clear, intermediate and muddy ponds. Table 4 compares the average turbidities, with the average weight increments made by individual fish at the end of each of the two growing seasons. In order to consolidate the presentation, weighted averages were computed for the length and weight increments made in the three categories of ponds and the comparisons presented graphically in Figure 2. By the end of the first growing season the bass in the clear ponds had increased their individual weights approximately 6.4 times, those in the intermediate approximately 4 times, and those in the muddy ponds only 1.26 times. Corresponding growths in inches were 4.5 for the clear, 3.4 in the intermediate, and 1.5 in the muddy ponds. By the end of the second growing season the original bass in the clear ponds had increased their average weight approximately 14

Table 3. Average yields in pounds per acre of three size categories of fish from four clear, four intermediate, and four muddy ponds.

Type ponds	Largemouth bass		Redear sunfish		Bluegill				
	10 inches or longer	6 to 10 inches	Less than 6 inches	6 inches or longer	3 to 6 inches	Less than 3 inches			
Clear	14.0	4.1	9.5	12.8	10.9	109.6	7.3	65.2	62.6
Inter-mediate	18.5	0.5	13.0	15.9	11.9	34.2			
Muddy	2.6	8.0	1.5	8.6	4.7	0.2	14.1	4.2	2.6

-25 PPM 25-100 PPM 100-388 PPM

Figure 2. Average weight gains made by fish in 12 clear, 12 intermediate, and 9 muddy ponds as indicated by samples obtained at end of each of two growing seasons.

Table 4. Average weight gains by individual fish from samples obtained at end of first growing season (1) and second growing season (2) in farm ponds, compared with average turbidities.

Pond no.	Average turbidity	Average weight gain in hundredths of pounds											
		Largemouth bass						Redear sunfish				Bluegill	
		0.040 ¹		0.063 ¹		0.111 ¹		0.023 ¹		0.034 ¹		0.058 ¹	
		Year (1)	Year (2)	Year (1)	Year (2)	Year (1)	Year (2)	Year (1)	Year (2)	Year (1)	Year (2)	Year (1)	Year (2)
1	-25					.42	---					.17	---
2	"			.57	1.55			.23	.24				
3	"			.53	1.44			.15	.23				
4	"					.35	.63					.19	.18
5	"	.67	2.06							.13	.15		
6	"					.37	.83					.18	.19
7	"	.47	1.07							.16	.19		
8	"					.43	.60					.20	.19
9	"	.29	.42							.08	.13		
10	"			.35	---			.12	---				
11	"			.67	1.19			.10	.15				
12	"	.35	.53							.11	.20		
13	45	.46	---							.12	.19		
14	46			.42	1.08			.10	.17				
15	50	.37	---					.09	---				
16	58					.26	.72					.09	.16
17	64	.17	.50					.09	.19				
18	71					.31	.94			.21	.33		
19	76					.22	.40			.10	.21		
20	83					.40	---					.18	.29
21	86	.38	.77							.11	.15		
22	94	.20	.68							.06	.17		
23	99			.12	.14							.08	.11
24	100			.39	.43			.13	.22				
25	107			.17	---			.09	---				
26	122					.03	.24					.08	.25
27	132					.02	.07			.05	.12		
28	148			.20	.38			.08	.21				
29	185					.06	.28					.07	.24
30	203	.09	.14							.04	---		
31	239			.13	.22			.09	.15				
32	339			.05	.07			.10	.12				
33	388			.10	---			.03	---				

1 These numbers denote average weight (in hundredths of pounds) of fish when stocked.

times, those in the intermediate 7.1, and those in the muddy 2.5 times. Growths in inches averaged 6.9, 5.1, and 2.4 respectively. The trend of the first year was consistent through the second year, with turbidity remaining a dominant influence.

The first year's results for bluegills and redears were consistent with those for bass, but intraspecific competition and mortality had a marked influence on growth data for sunfishes obtained at the end of the second season. Figure 2 shows that first-year growth for both species decreased directly as turbidity increased but that at the end of the second year the adults recovered from the turbid ponds were as large or larger than those recovered from the clear ponds. The apparent inconsistency is explained by (1) mortality and/or removal by anglers during the second growing season of the faster-growing individuals in the clear ponds and (2) by intraspecific competition, since the rate of reproduction and size of population was also directly proportional to clarity of the waters. That the faster growing adults had died or been removed from the clearer ponds became apparent when the average size of adults recovered at the end of the second growing season were little different, and in one instance smaller, than the average size computed from samples obtained at the end of the first growing season. This was apparent only in the clearer ponds, however, and particularly so in the bluegill populations (last column, table 4). The influence of intraspecific competition was apparent in both redear and bluegill populations, but particularly so in the latter. The sunfishes in the clear ponds made significantly greater growths during the first year when populations were comparatively small, but tended to lose this advantage during the second season due to the greater abundance of young in the clearer ponds.

Pond No. 29 may be used in illustration. This was the most turbid pond (average turbidity: 185 ppm) in which bluegills were stocked and produced the poorest first-year growth of all bluegill ponds. However, Pond 29 also had the poorest reproduction rate among the bluegill ponds. The estimated total weight (10.9 pounds) of young (both 1954 and 1955 spawn combined) was considerably less than the weight of the surviving adults (17.4 pounds). It follows that the few adults in this pond enjoyed less competition than bluegills in any other pond during the second growing season and increased their average weight from a ranking of last at the end of the first year to a ranking of second highest at the end of the second year. The influences of turbidity are therefore more clearly pictured by comparative growths made during the first year when all populations were comparatively small. Certainly turbidity was equally restrictive during the second season, but the effects were masked by other factors.

Relation of Turbidity to Spawning Success

As indicated previously, turbidity had a marked influence on reproduction. Occurrence or non-occurrence was based on returns from the fall samplings. A high degree of confidence was placed in the returns since the turbid ponds from which no young were recovered were in most cases the shallowest, the freest from vegetation, and the least difficult to seine and particularly because second-year returns agreed in all instances with those from the first year. At the end of the first summer, young bass were found in 7 of 12 clear ponds, four of 12 intermediate ponds, and in 0 of 9 muddy ponds. The most turbid pond from which young bass were recovered in 1954 averaged 84 ppm. Redears indicate a greater tolerance than bass, spawning successfully in 8 of 9 clear ponds, 9 of 9 intermediate ponds, and in 1 of 7 muddy ponds in

which they were used. The highest turbidity from which young redears were recovered averaged 174 ppm through 1954. The older and larger bluegills spawned successfully in all nine ponds in which they were stocked, including two ponds having turbidities of 124 and 185 ppm.

There was some question at the end of the first year as to whether turbidity had directly prevented successful spawning or whether the turbidity and associated conditions had retarded growth and development of the fish to the extent that they were physically incapable of reproduction. Evidence gained during the second season seems to support the latter supposition in part. The returns show that in 1954 bass reproduction was found in only 4 of 12 intermediate ponds but that all 11 ponds of this group still in use produced young bass in 1955. Among the muddy ponds reproduction was found in 0 of 9 in 1954, but young bass were recovered from 3 of the 7 ponds still in use through 1955. Redears spawned successfully in two muddy ponds in 1955 in which they had failed to produce in 1954 but had still produced no young in two of the muddy ponds by the end of the second year. It is highly doubtful that these redears could have spawned successfully in any subsequent year under the same pond conditions since they had now lived through three growing seasons and had attained average lengths of 6 inches or greater. There seems less reason to expect that the bass could have spawned in the most turbid ponds in subsequent years since they seemed more severely limited by turbidity than the redears. The best interpretation would seem to be that within some of the intermediate ponds reproduction was merely delayed one year through retardation of growth and development of the parent fishes but that conditions were such in some of the muddy ponds that successful reproduction was not possible.

It was of further interest to note the relation of size-of-bass-when-planted

to subsequent spawning success. The author entertained some doubt that the bass would reproduce during the first year since they were stocked rather late in the spawning season (May 12 and 19) and at sizes considered near or below the minimum at which bass can successfully reproduce. Bass of three sizes were used, all of which were one year old. In the group averaging 4.9 inches, the range was 4.1 to 6.1 inches. This size was stocked in four clear, in three intermediate, and in one muddy ponds. No reproduction was found in any of these at the end of the first year. In the size group averaging 5.4 inches, the range was 4.9 to 6.5 inches. Reproduction was found in 3 of 4 clear ponds, 1 of 4 intermediate ponds, and in 0 of 5 muddy ponds in which this size was stocked. In the group averaging 6.6 inches, none of the bass was longer than 7.6 inches. Reproduction was found in 4 of 4 clear ponds, 3 of 6 intermediate ponds, and in 0 of 3 muddy ponds in which they were used. In the 11 ponds exhibiting reproduction, the size range of the recovered young was 1.7 to 6.4 inches; the average was about 3.6 inches. Recovered young in the seven clear ponds had an average length of 3.7 inches, compared to 3.5 inches for the young found in the four ponds of intermediate turbidity.

The previous discussion has considered only the occurrence and not the rates of reproduction. Table 5 gives the total weights of young recovered from the 12 ponds for which total populations were estimated. For redears the average production in clear ponds (100.3 pounds per acre) in 1955 was approximately 3 times that in the intermediate ponds (32.5 pounds per acre), and over 300 times that from the muddy ponds (0.33 pounds per acre). Weight of young bluegill in clear ponds was approximately 18 times that in the muddy ponds. It should be pointed out that only two clear and two muddy ponds are

Table 5. Weights in pounds per acre of 1954 and 1955 year classes as determined from final population estimates made at end of 1955 growing season.

Pond no.	Average turbidity	Largemouth bass		Redear sunfish		Bluegill	
		1954	1955	1954	1955	1945	1955
4	-25	0.86	12.9			100.6	73.7
6	"	3.5	3.5			46.3	36.0
7	"	0.0	23.3	23.8	99.3		
9	"	0.0	3.7	10.1	101.2		
14	46	0.0	20.6	30.1	11.7		
17	64	0.0	11.9	21.0	47.0		
19	76	0.0	24.2	3.4	59.7		
22	94	1.4	4.8	7.7	11.7		
26	122	0.0	4.6			3.5	4.1
27	132	0.0	0.0	0.0	0.66		
29	185	0.0	0.0			7.4	0.83
32	339	0.0	0.0	0.0	0.0		

compared for the sunfishes, but less complete records obtained by seining other ponds confirmed these general proportions. The data show a higher average weight of young bass in intermediate ponds than in the clear ponds. It is of course impossible to separate completely the various causal factors in such returns. It is possible that the intermediate turbidities may in some way favor the reproduction and/or survival of bass, as has been suggested by Doan (1941) for sauger. In this instance, however, competition from the companion sunfishes in the manner described by Bennett (1954) is believed to have had an important influence on the yield of bass since the weights and numbers of young sunfishes were vastly greater in the clear than in the intermediate ponds.

An attempt was made to determine the level of turbidity above which reproduction became severely restricted. The exact level of course was not determinable because such factors as age of pond and condition of the bottom seemed to have additional influence. It was observed, for instance, that newer ponds with firm, unsilted bottoms produced young at higher average turbidities than older ponds having soft, silt-laden bottoms. The greater fertility common to new ponds was undoubtedly an additional factor. The accuracy of the determination was further limited by the fact that turbidities of individual ponds varied considerably from time to time. A completely accurate determination could be made only by use of completely controlled conditions and by observing the turbidity at the exact time of spawning. Since dates of spawning were not observed and since they undoubtedly varied from pond to pond, particularly for the sunfishes, the average turbidities compiled over the two year period are believed to offer the most reliable basis for this determination. Upon this basis, the critical level appeared to lie between

75 and 100 ppm for all three species, with 100 ppm as the approximate level above which spawning success was severely restricted, or non-existent. The critical limit for bass appeared to be somewhat below that for the sunfishes. Successful reproduction was achieved in the newer, hard-bottomed ponds at somewhat higher turbidities than in older ponds, but reproduction was generally of low proportions when turbidities exceeded 100 ppm. As mentioned previously, a small number of young bass and redear were recovered from one pond having an average turbidity of 239 ppm. This was somewhat surprising since no young were recovered from several ponds having much lower turbidities. It is believed possible that these young fish were stocked by one of the many persons having an interest in the pond since it was located in a comparatively urban area, and both young bass and redears were available from adjacent ponds.

Table 5 shows that Pond No. 19 was the most turbid (average turbidity: 76 ppm) from which a reasonably large weight of young bass was recovered. This yield was at the rate of 24.2 pounds per acre of young of the year bass, which represented an estimated 1300 individuals per acre averaging 3.0 inches in length. The next most turbid pond (94ppm) yielded only 4.8 pounds, or 650 individuals per acre with a smaller average length of 2.6 inches. The next record is for a pond having an average turbidity of 122 ppm, from which the yield was 4.6 pounds per acre, representing 87 individuals with an average length of 4.6 inches. A very limited number of young bass were seined from one other pond having an average turbidity of 148 ppm, and no reproduction was found in any pond having a higher turbidity with the exception of the single pond mentioned above.

Pond No. 19 with an average turbidity of 76 ppm also yielded fairly large numbers of young redears (Table 5), but production dropped notably in more

turbid ponds. Complete population estimates were not made for any bluegill pond within the intermediate range, but 83 ppm was the most turbid water from which large numbers of small bluegills were recovered by seining, and weights and numbers decreased markedly in more turbid ponds.

Plankton Production

In a correlated study (Claffey, 1955), 20 of the Payne County ponds were sampled once each month for 6 months of the 1954 growing season (April to October) to determine the abundance of microscopic fish food. Volume of net plankton in the surface waters (0 to 2 feet) in clear ponds (average: 0.0192 milliliters per liter) was 8 times greater than in ponds having intermediate turbidities (average: 0.0024 milliliters per liter), and 12.8 times greater than in muddy ponds (average: 0.0015 milliliters per liter) (See Figure 3). Less intensive investigations in 1955 showed small average differences due to larger concentrations of plankton (chiefly zooplankton) in the surface waters of a few turbid ponds.

Light penetration appears to be the principal limiting factor in productivity of turbid waters. Using a spectrophotometer, Claffey (1955) found that in water having a turbidity of 25 ppm, only 24.9 percent of the original light of the red wave lengths (the most penetrating) was visible at a depth of 4 inches; at 50 ppm, only 6.3 percent. At turbidities of 150 ppm, no light of any visible wave length penetrated through a depth of 3 inches.

HATCHERY POND EXPERIMENTS

The use of hatchery ponds was desirable because: 1) the farm ponds exhibited individual variations in productivity due to differences in fertility and physiography of the basins and watersheds which could not be fully evaluated;

Figure 3. Average volumes of net plankton in surface waters of three categories of farm ponds as determined from monthly samples taken from April to October, 1954.

and 2) the use of morphologically similar hatchery ponds would minimize these natural variables and would facilitate a more complete return of the fish populations through draining. The desired turbidities were then to be created by artificial means, simulating as nearly as possible the range of turbidities found in the farm ponds. It was hoped that by starting with morphologically similar ponds the final results could be attributed more definitely to the effects of the induced turbidities.

This work was done at the State Fish Hatchery at Durant, Oklahoma. The ponds used were rectangular in shape, with average dimensions of 61 by 69.5 feet, holding an average of approximately 0.1 (range: 0.084 to 0.111) acre of water. Maximum depths were occasionally as low as 2.5 feet, due to evaporation, but the ponds were periodically raised to depths of 3.5 feet. The average depths were maintained at approximately 1.5 feet. The water supply for the hatchery is pumped from the Blue River. The water is ordinarily clear (less than 25 ppm), having the chemical characteristics shown in Table 6.

METHODS AND PROCEDURES

It was hoped initially^s that some natural soil material could be found that would remain in suspension in the pond waters and that the turbidities could be controlled by the amount of such material added. However, all materials used rapidly settled out, apparently due to a high availability of positive ions in the water causing the neutralization and flocculation of the negatively charged clay colloids in the manner described by Irwin and Stevenson (1951). An attempt was then made to find some agent that could prevent or retard coagulation of the soil materials. After considerable experimentation in the laboratory, the use of sodium silicate was found to be

Table 6. Chemical characteristics of Blue River, near Blue, Oklahoma, as determined by four examinations made in the months of March, April, June and July, 1955.¹

	Average ppm.	Range ppm.
Calcium	41.8	28-56
Magnesium	23	13-32
Sodium	8.6	6.5-12
Chloride	13	7. -19
Bicarbonate (HCO_3)	226	160-264
Carbonate (CO_3)	...	...
Hardness as CaCO_3 : Total	199	140-240
Noncarbonate	13.8	4-24
Specific conductance (micromhos at 25°C)	379	271-453
pH	7.8	7.5-7.9

¹ From unpublished records of the U. S. Geological Survey.

fairly effective. Tests showed that the use of 1.2 cubic centimeters of the chemical with 10 grams of clay soil per gallon of pond water caused the finely divided soil to remain long in suspension.¹ The chemical had the effect of a

¹The material was mostly unweathered subsoil mined approximately 6 miles south of the hatchery in an area having tight, alkaline clay soils.

dispersing agent, probably by forming a protective coating around the soil colloids and greatly retarding their flocculation. The substance is relatively inert and has no obvious effect on fishes, plankton, insects, or other aquatic organisms. Four ponds were treated with combinations of clay and the chemical, and two additional ponds were treated with the chemical only (Table 7). It was found, however, that the turbidities could be controlled only within broad ranges. This was believed partly due to the individual characteristics of the ponds, and also to a lack of uniformity in the soil material. Such large quantities were involved that it was impossible to standardize the soil beyond the crude selections made in the field. The soil was trucked to the ponds and finely divided in 55 gallon drums by use of water pressure from a two-inch pump. The sodium silicate was also added to the barrel, and this highly turbid mixture was then pumped into the pond. The original turbidities were high, but they lessened over a period of weeks until additional treatment was needed.

Since there was some doubt that the use of the chemical would prove successful, it was decided to muddy an equal number of ponds by use of carp. Five adult carp were added to each of six ponds (Table 7). The possibility of reproduction was eliminated by using only males or females together in the same pond. Attempts were made to control the turbidities by the weight of carp used in each pond and by the amount of clay soil added to the ponds.

Table 7. Rates of growth, survival, and total weights of largemouth bass, bluegill and channel catfish in hatchery ponds of different turbidities and treatments.

Pond no.	Treatment	Turbidities		Largemouth bass		Bluegill			Channel catfish		All species pounds per acre
		Aver-	Maxi-	Average growth in inches	Pounds per acre	Average growth in inches	Young adults	Young plus adults	Average growth in inches	Pounds per acre	
3	None	-25	-25	3.5	48	3.3	5.5	69	5.1	24.5	142
4	None	-25	-25	3.1	42.8	3.2	1.2	75.6	4.8	29.2	148
14	Chemical ¹	-25	73	2.4	28.3	1.5	33.7	79.3	3.3	11.9	120
	Averages			3.0	39.4	2.7	13.5	74.6	4.4	21.9	137
7	Carp ⁴	47	85	1.8	14.8	1.9	39.5	73.9	4.0	32.0	121
13	Chemical ¹	62	111	2.9	19.2	1.2	11.9	42.8	4.6	20.6	83
16	Carp ⁷	64	140	2.1	18.6	.5	5.0	34.6	2.9	27.0	80
8	Carp ⁵	66	135	3.1	17.2	1.4	24.9	56.4	3.6	20.9	95
5	Chemical ²	72	182	2.4	21.4	2.5	15.7	55.7	3.4	14.8	92
15	Carp ⁶	74	180	1.6	11.5	.7	53.4	67.6	3.0	25.3	104
12	Carp ⁶	91	180	2.3	15.9	.9	26.3	38.9	3.3	27.6	82
	Averages			2.3	17.0	1.3	25.2	52.8	3.5	24.0	94
6	Chemical ²	110	170	2.8	27.7	2.7	8.7	56.5	3.3	16.2	100
11	Carp ⁵	112	230	2.5	9.9	.8	47.6	59.8	3.2	27.3	97
9	Chemical ³	175	270	2.5	18.5	1.5	15.7	71.4	3.9	31.8	122
10	Chemical ³	203	400	2.6	20.2	1.2	1.2	24.1	4.0	30.5	75
	Averages			2.6	19.1	1.6	18.0	52.9	3.6	26.5	98

For footnote key, see Table 7a.

Table 7a. Percent recovery of largemouth bass, bluegill and channel catfish in hatchery ponds of different turbidities and treatments.

Pond no.	Treatment	Turbidities Average Maximum	Largemouth bass Percent recovery	Bluegill Percent recovery	Channel catfish Percent recovery
3	None	-25	62	48	32
4	None	-25	67	63	44
14	Chemical ¹	73	76	49	30
	Average		68.5	53	35
7	Carp ⁴	47	57	73	68
13	Chemical ¹	62	38	46	34
16	Carp ⁵	64	60	73	90
8	Carp ⁵	66	29	41	50
5	Chemical ²	72	55	56	36
15	Carp ⁶	74	56	33	88
12	Carp ⁶	91	48	22	76
	Averages		49	49	63
6	Chemical ²	110	56	56	42
11	Carp ⁵	112	24	24	80
9	Chemical ³	175	46	77	68
10	Chemical ³	203	42	30	56
	Averages		42	47	62

- Received total of 10 gallons of sodium silicate in two treatments.
- Received total of 17 gallons of sodium silicate and 1600 pounds of soil in four treatments.
- Received total of 20 gallons of sodium silicate and 1900 pounds of soil in four treatments.
- Received 5 carp with initial total weight of 17.7 pounds plus 500 pounds of soil.
- Received 5 carp with initial total weight of 15.0 pounds plus 500 pounds of soil.
- Received 5 carp with initial total weight of 22.8 pounds, no soil.
- Received 5 carp with initial total weight of 30.0 pounds, no soil.

Again the attempts at control were quite ineffective. The addition of clay had no observable effect on turbidity in the absence of the chemical, and there was little or no correlation between weight of carp used and turbidities created.

The final alignment was now six ponds treated with chemical, six with carp, and two left untreated as controls. The six ponds receiving the chemical were first muddied May 11-14, the carp were added on May 18, 1955. Each pond was stocked with 125 largemouth bass, 100 bluegill and 50 channel catfish. The bass were young of the year with an average length of 1.9 inches (range: 1.7 - 2.1). Both the bluegills and the channel catfish were yearling fish - the bluegills averaging 3.1 inches (range: 1.9 - 4.5), and the channel catfish 3.5 inches (range: 2.7 - 4.2). The bluegills were stocked on April 28, the bass and channel catfish on May 17 and 18. The ponds were revisited once each third week throughout the summer to take plankton and turbidity samples and to check the need for further treatment. Ponds 5, 6, 9 and 10 were given additional treatments on May 25, July 25, and August 25, 1955, to maintain their turbidities, and the water levels of all ponds were raised at these times. Eight of the clearer ponds also developed excessive growths of vegetation (mostly bushy pondweeds, Najas spp.), which were twice thinned to prevent the ponds from being overgrown. The ponds were drained during the period October 31 to November 2, 1955.

FINDINGS FROM THE HATCHERY PONDS

As in the farm ponds, the clear hatchery water produced notably faster growths, as well as greater total weights of bass and bluegill (Table 7). It was found, however, that channel catfish production was greater in the

muddy than in either clear or intermediate ponds. The average total production (all three species combined) in the three clear ponds was at the rate of 137 pounds per acre, as compared with 94 in the intermediate ponds and 98 in the most turbid ponds. The greater production in the clear ponds was attributable to a greater weight of bass and bluegills. The larger total weight of fish in the most turbid ponds as compared to the intermediate ponds was due principally to the faster growth and higher survival of catfish in the muddier ponds and, to a lesser degree, to a slightly larger production of bass in the muddy than in the intermediate ponds. This last was attributed to the direct influence of carp on bass, however, since only 1 of the 4 muddy ponds (Table 7) contained carp, while carp were present in 5 of the 7 intermediate ponds. The same competitive influence accounts for the faster growth by the parent bluegills in the muddy ponds (Table 7). The final total weights of bluegills were approximately equal in the intermediate and muddy ponds, however, due to the consistently greater production of young bluegill in the carp ponds than in either the most turbid ponds without carp or in the clear, untreated ponds (Nos. 3 and 4, Table 7).

The influences of turbidity on growth, survival and total production are more clearly illustrated by Table 8, which includes only those ponds not containing carp and which eliminates the influence of competition by this species. Again, the higher recovery from the clear ponds was due to greater production of bass and bluegill, and the greater weight in the muddy than in the intermediate ponds was due to the faster growth and greater survival of catfish in the muddiest ponds. For both bass and bluegills the relationship was direct and consistent throughout; i.e., as turbidity increased, the rates of growth, rates of survival, and total weights decreased. Rates of survival

are significant here due to their intimate relation to the companion values. For example, the greater growth by bass in the clear ponds is of added significance since the survival rates also were higher in the clear than in the intermediate or muddy ponds.

Table 8. Growth, survival, and total weights of largemouth bass, bluegill and channel catfish in relation to turbidity in hatchery ponds. Figures in parenthesis denote percent recovery of original number stocked.

Pond no.	Average turbidity	Largemouth bass		Bluegill ¹		Channel catfish		Pounds per acre all species
		Average growth in inches	Pounds per acre	Average growth in inches	Pounds per acre	Average growth in inches	Pounds per acre	
3	-25	3.5 (62)	48	3.3 (48)	69	5.1 (32)	24.5	142
4	-25	3.1 (67)	42.8	3.2 (63)	75.6	4.8 (44)	29.2	148
14	-25	2.4 (76)	28.3	1.5 (49)	45.6	3.3 (30)	11.9	120
Averages in clear ponds		3.0 (68)	39.7	2.7 (53)	63.4	4.4 (35)	21.9	137
13	62	2.9 (38)	19.2	1.2 (46)	30.9	4.6 (34)	20.6	83
5	72	2.4 (55)	21.4	2.5 (56)	55.7	3.4 (36)	14.8	92
6	110	2.8 (56)	27.7	2.7 (56)	56.5	3.3 (42)	16.2	100
Averages in intermediate ponds		2.7 (50)	22.8	2.1 (53)	47.7	3.8 (37)	17.2	92
9	175	2.5 (46)	18.5	1.5 (77)	71.4	3.9 (68)	31.8	122
10	203	2.6 (42)	20.2	1.2 (30)	24.1	4.0 (56)	30.5	75
Averages in muddy ponds		2.6 (44)	19.4	1.4 (36)	47.8	4.0 (62)	31.2	99

¹Growth figures are for adults only; total weights include adults plus young.

The channel catfish again yielded the greatest total weight from the most turbid ponds, but other relationships appeared inconsistent. Table 8 shows that the clear ponds exhibited the fastest growth rates and the lowest rates of survival, while both survival and total weights were the greatest in the most turbid ponds. Catfish in the intermediate ponds survived at approximately the same rate as in the clear ponds, but had a slower growth and smaller total weight than either the clear or muddy ponds. One would expect the growth rate in the intermediate ponds to rank in an intermediate position consistent with the survival rate and degree of turbidity. That it did not may be due to some unknown food relationship in the ponds, or to some little understood characteristic of the species. It may be that the channel catfish is able to exploit the greater abundance of food in clear ponds by sight feeding, and can rely quite successfully on its sensory aids in the very turbid ponds, while enjoying neither advantage within certain intermediate ranges of turbidity. It seems clear, however, that catfish production was considerably enhanced by the muddy waters. While growth was somewhat faster in the clear ponds, this was more than compensated for by the much greater rate of survival and greater total weight produced in the muddy ponds.

In spite of the morphological similarities of the ponds, the use of a common water supply, their side-by-side location, and other standardizing influences, the various ponds exhibited rather marked individual characteristics. For example, ponds 13 and 14 were immediately adjacent, differed in size by only approximately 0.007 of an acre, and received identical treatments; however, pond 14 remained clear throughout the investigation, and pond 13 maintained an average turbidity of 62 ppm. Ponds 11 and 12 also failed to conform to expectations. Pond 12 received the greater initial weight of carp by approximately

8 pounds (equivalent to 80 pounds per acre), yet it remained clearer than pond 11. Other examples may be observed in the tabled data. Despite these variations, the carp and the chemical were considered generally effective for the purposes intended.

The use of the chemical deserves some further discussion. It cannot be categorically stated that it had no effects beyond its intended function of sustaining the turbidities. That the effects were limited, however, seems evident from these considerations:

- 1) The chemical had no observed influence on pH of the pond waters, or on the production of plankton, aquatic insects, or other invertebrate forms.
- 2) Survival of bass and bluegills was higher in the chemically treated ponds than in the ponds made turbid by carp.
- 3) Pond 9, which received a maximum amount of the chemical, produced a greater weight of fishes than other ponds receiving lesser amounts. It was generally true, however, that production decreased with increase in turbidity, and an increase in turbidity was in most cases proportional to the amount of chemical used.
- 4) While it was true that bluegill reproduction was greater in the carp ponds than in the chemically treated ponds, it was also true that the carp ponds yielded greater weights of young bluegills than the untreated, clear ponds.

Additional evidence can be marshalled on both sides of the question. Since the effects were minimal, and the variations could be attributed to the demonstrated individualities of the ponds, and since the results conform closely with those from the farm ponds, the direct effects of the chemical are believed to

have been insignificant and to have had no important influence on the experiment.

The presence or absence of carp had little influence on total weight of the companion fishes. Considering only the 11 turbid ponds (Table 7), the average weight of bass, bluegills and channel catfish combined was 97 pounds per acre in the carp ponds and 92 pounds per acre in the ponds without carp. The greater weight in the carp ponds was due to a greater weight of channel catfish and young bluegills, which more than compensated for a smaller weight of bass and adult bluegills. Considering the species separately, the carp exerted varying influences. Growth of bass and adult bluegill was less in the carp ponds than in the turbid ponds without carp, in spite of their lower average turbidity. Total weight of bass was also less in the carp ponds, but total weight of bluegills was greater due to the abundance of young produced in the carp ponds. Channel catfish production averaged higher in the carp ponds than in either the clear or the turbid ponds without carp, due to the much higher survival (75 percent, as compared with 35 in the clear, and 47 in the turbid ponds without carp). The evidence that the presence of carp in some way enhances the production of catfish is too strong to ignore. The beneficial influence may be due to the elimination of aquatic weeds by carp and/or their reduction in numbers of aquatic insects known to prey on young catfish. The greater yield of young bluegills in the carp ponds may have been brought about in the same way.

Weight gains by carp had no apparent relation to turbidity within the rather small range of turbidities created. As might be expected, the gains were generally proportional to the initial weight of carp stocked (Table 9). The small gains in weight made by carp in ponds 15 and 16 suggests that the initial weights stocked were near the carrying capacity of these ponds for

Table 9. Weight gains of carp in relation to turbidities and weights of companion fishes.

Pond no.	Average turbidity	Pounds per acre			Companion <u>species</u>	All <u>species</u>
		Initial	Final	Gain	Pounds per acre	Total pounds per acre
7	47	177	240	63	121	361
8	66	150	270	120	95	365
11	112	150	223	73	97	320
12	91	228	270	43	82	352
15	74	228	247	19	104	351
16	64	300	320	20	80	400

this species. It seems significant, however, that total weights of the companion fishes in these ponds were little different from ponds having lesser weights of carp, or having no carp at all, emphasizing that total carrying capacity may not always be revealed by the yield of a single species, or even a combination of species, unless all the resources of the pond are utilized. It seems clear that the carp populations were superimposed on the populations of companion fishes in such a way that competition between the two was at a minimum.

RESERVOIR STUDIES

The reservoir phase of the study was designed to provide comparative data from two large bodies of water, one muddy, the other clear. The very muddy Heyburn Reservoir and the clear Upper Spavinaw Reservoir were made the chief subjects of study, with supplemental data from other reservoirs.

Heyburn is a 1,070-acre Corps of Engineers flood-control project impounded in late 1950 on Polecat Creek, Creek County, Oklahoma. Heyburn was a natural choice as a turbid reservoir since it has been continuously turbid throughout most of its impoundment. From the period September, 1952, through September 1955, surface turbidities at the dam ranged between a high of 300 ppm in March, 1954, to a low of 51 ppm in August, 1955. The average turbidity through the summer of 1954 was 136 ppm; for the summer of 1955, 126 ppm. The lake is shallow (10 feet average depth, 42.5 maximum) and divides a short distance above the dam to form two narrow, winding arms. The bottom consists chiefly of partially cleared mud flats. The high turbidity imparts a yellowish-brown color which is distinctly unattractive. The terrain is moderately hilly, the region is very poor agriculturally, and erosion is severe.

Upper Spavinaw, impounded in January, 1952, is one of two water-supply reservoirs constructed and operated by the City of Tulsa on Spavinaw Creek, Delaware County, Oklahoma. The 3,192-acre lake formed has an average depth of 25 feet and a maximum depth of 90 feet. It resembles a long, narrow, slightly crooked finger, with margins roughly serrated by numerous coves. Relatively flat shorelines, shallow waters, and silted, mud bottoms are restricted almost entirely to a small headwater region. Siltation has been slight, and the reservoir has remained clear since impoundment.

It is recognized that broad ecological differences are associated with the differences in turbidities and that turbidity is only one of several factors of possible influence on the biology of the two reservoirs. It is believed, however, that differences in turbidities were closely related to differences in growth, relative abundance, and reproductive success of certain species studied, as well as for differences in plankton production, rates of fisherman use, and fishing success, in the two reservoirs.

FINDINGS FROM THE RESERVOIR STUDIES

Results from the clear and muddy reservoirs were consistent with those from the clear and muddy ponds. The clear reservoir exhibited faster growth by all species in a population dominated by gizzard shad, largemouth bass and bluegill, as contrasted with a slower-growing population in the muddy reservoir having catfish, carp, carpsuckers and stunted white crappies as the principal fishes. Young-of-year bass, crappies and other scaled fishes were generally scarce in the muddy reservoir and there was an abundance of young catfishes. The reverse was found in the clear reservoir.

Largemouth bass

Growth of largemouth bass in Heyburn Reservoir was slower than in Upper Spavinaw, as well as in all other Oklahoma reservoirs of similar age and size for which data were available (Table 10). While average first-year growth was greater at Heyburn than at Canton Reservoir, this advantage was lost during the second and third growing seasons. The comparisons in Table 10 are restricted to new (impounded five years or less) Oklahoma reservoirs of over 500 surface acres. Here, as in subsequent comparisons, the growth figures represent weighted averages for the various years of growth. For example, the figure presented in Table 10 as first-year growth for Heyburn represents a weighted average of first-year growths made during five different growing seasons. This growth was remarkably uniform at Heyburn, averaging 5.2 inches for the four years 1950 through 1953, dropping to 4.1 in 1954. First-year growth in Upper Spavinaw averaged 6.4 inches. These results agree with those of Jenkins and Hall (1953) who found growths of bass to be consistently faster in Oklahoma lakes known to be usually clear than in those known to be consistently turbid.

The history of the Heyburn largemouth bass population is unique. Outstanding characteristics have been the preponderance of relatively old bass and the scarcity of young bass -- an extremely unusual condition in new reservoirs. In 1952 and 1953 Orr (personal correspondence) collected 93 bass of which 72 percent were of the 1950 year class, and 20 percent were of the 1951 year class. When collected, 92 percent of Orr's fish were in their third year or older, and yearling bass were completely absent from the 1953 collections at a time when, in a normal population structure, they should have been dominant. The results in 1954 and 1955 were very similar.

Table 10. Largemouth bass growths at Heyburn and Upper Spavinaw compared with growths made in other new Oklahoma reservoirs.

Name of reservoir	Condition	Size in acres	No. of fish	Dates collected	Average calculated total length in inches at end of year			
					1	2	3	4
Heyburn	Muddy	1,070	182	52-55	5.2	9.6	13.1	15.5
Upper Spavinaw	Clear	3,192	355	52-55	6.4	11.7	15.5	
Ft. Gibson ¹	Clear	19,100	132	1953	7.5	11.3		
Tenkiller ²	Clear	12,500	142	53-54	7.9	16.4		
Clear Creek	Clear	800	154	50-51	8.2	14.1	17.1	
Canton ³	Intermediate	4,900	558	49-51	4.5	10.8	15.5	
Wister ³	Intermediate	4,000	222	51-52	6.9	11.2	14.5	17.7

- 1 Unpublished data on file at the Oklahoma Fisheries Research Laboratory.
- 2 Data from Oklahoma Fisheries Research Laboratory Report No. 32, October, 1953.
- 3 Growths at Canton and Wister were based on calculated body-scale relationships and probably average slightly higher in the younger age groups than if calculated by the direct proportion method used in all other samples. These and the Clear Creek data were taken from Jenkins and Hall (1953).

Of 56 bass collected in 1954, 64 percent were in their fourth year or older, 32 percent were in their third year, and only one yearling fish was taken. The samples were mostly taken by rotenone, undoubtedly the least selective of any available method. In 1955, 35 bass were aged of which 23, or approximately two-thirds, were in their third year or older and only 12 were second-year fish. Young-of-the-year bass were extremely scarce at Heyburn in 1954 and 1955. Extensive seining in all areas and the nine rotenone samples yielded only 57 young in 1954, and 39 in 1955. All evidence points to a small population dominated by slow-growing, older bass, with very limited recruitment through natural reproduction. It seems extremely doubtful that the population

will be able to sustain itself in the face of increasing turbidities. The largemouth bass population at Upper Spavinaw contrasted sharply with that of Heyburn. Young-of-the-year were extremely abundant both years. The population of fingerling bass in the 10-acre cove rotenoned on June 21, 1955 was conservatively estimated at 21,780 individuals, ranging from 1.4 to 2.5 inches total length. In 1954 yearling bass (1953 year class) in sizes of 6 to 11 inches could be seen throughout the lake on any day, with several schools often simultaneously in view wildly thrashing the surface as they fed upon small fish. This large year class dominated the angler catch throughout 1955. They continued to school throughout the second summer but were commonly seen only in the early morning and almost always in the deep, open, central regions of the lake. Here large numbers of boats converged each morning since the bass were easily caught by placing almost any type of lure near the feeding, surfacing schools.

White crappie

Growth of Heyburn white crappies was also the poorest of any Oklahoma reservoir of similar age and size (Table 11). Average second-year length was 5.0 inches, more than 3 inches less than the next slowest growth recorded from other new Oklahoma reservoirs. First-year growth for four specimens of the 1954 year class collected at Upper Spavinaw was 7.7 inches, and for 8 individuals of the 52 year class 7.9 inches; however, the collections were dominated by the more abundant 1953 year class which had an average first-year growth of only 3.4 inches. Again the results agree with investigations in Oklahoma (Hall, Jenkins and Finnell, 1954) which found growth consistently slower in 31 turbid than in 45 clear Oklahoma lakes.

In both 1954 and 1955 at Heyburn, the white crappie was the most abundant fish (and very often the only fish) returned in hoop nets, gill nets, and wire

Table 11. White crappie growths at Heyburn and Upper Spavinaw compared with growths made in other new Oklahoma reservoirs.¹

Name of reservoir	Condition	Size in acres	No. of fish	Dates collected	Average calculated total length in inches at end of year			
					1	2	3	4
Heyburn	Muddy	1,070	446	52-55	2.8	5.0	7.3	
Upper Spavinaw	Clear	3,192	304	52-55	3.6	12.3 ²		
Ft. Gibson	Clear	19,100	479	52-53	2.8	8.6	10.9	12.5
Tenkiller	Clear	12,500	139	52-53	4.1	8.4	11.5	
Canton ³	Inter-mediate	4,900	1,552	48-53	4.1	8.3	10.3	11.7
Wister ³	Inter-mediate	4,000	346	49-52	3.9	8.3	10.5	12.6

1 Comparative data from Hall, Jenkins and Finnell (1954).

2 Represents only four individuals.

3 Growths from Canton and Wister Reservoirs were based on calculated body-scale relationships and probably average slightly higher in the younger age groups than if calculated by the direct proportion method used in the other calculations.

traps, and in both years it was outnumbered only by the gizzard shad in the rotenone samples. In spite of this prominence the population was not considered large. By weight it was less prominent, ranking seventh in the rotenone collections for both years.

The Heyburn white crappie population resembled that of the largemouth bass with a pronounced and unusual dominance of older fish, indicating again that natural reproduction was severely restricted. Orr collected and aged 234 white crappies in 1953 of which only 10, or less than 5 percent, were of the 1952 year-class at a time when this age group should have dominated the returns. In 1954, the 1952 year class represented a much greater percentage of the sample, and the 1953 year class was atypically scarce with only 8 of this age group among

a sample of 142 fish. That only the larger fish were being sampled is strongly suggested; however, the same age distribution was common to all types of samples, including those taken by rotenone. The explanation must be that each successive year class was smaller than the previous so that its size was small or large as compared with a more abundant, previous year class, or a smaller succeeding year class.

By 1955 the population had assumed a more normal structure due to a greater spawn of white crappies in 1954 than in previous years. Of the total of 74 fish aged, 56 were of the 1954, 8 of the 1953, and 10 of the 1952 year class. However, the 1954 year class was by no means large and gained its prominence only due to the weakness of the preceding year classes.

From the small numbers present in Heyburn, as compared with populations in other reservoirs, one would not consider the lake as overpopulated by this species. With consideration of the slow growth, however, one must assume that the numbers exceed the supply of food and/or other requirements, which is, in effect, overpopulation. It is therefore extremely doubtful that the white crappie will ever assume any importance to the Heyburn angler.

The black crappie is rare and of no significance in the Heyburn fishery. Known to have little affinity for turbid conditions, the species will probably disappear completely in future years. The situation was again different at Upper Spavinaw. Black crappies greatly outnumbered the white, and collections of both species during both years consisted chiefly of yearling individuals, rather than older fish. Wire trap catches in 1954 indicate the relative abundance of the two, wherein 136 lifts yielded 1,110 black crappies and only 124 white crappies.

Catfishes

The clear and turbid reservoirs differed significantly in abundance of channel and flathead catfishes. Both species are abundant at Heyburn, while only a single adult flathead and only two adult channel catfish have been recorded from Upper Spavinaw. The contrast is undoubtedly related to the differences in turbidity. In the first years of clear reservoirs, bass, crappies, and other scaled species apparently outproduce the catfishes and limit catfish survival through predation on their young. While individual pairs of catfish probably spawn as many young in clear as in turbid waters, the protection afforded by the turbid waters enables more to survive. The greater abilities of the catfishes to find food in the turbid environment increases this advantage, and the bass and crappies lose ground in the competition for food.

✓ In spite of its tolerance for turbid waters, growth of channel catfish at Heyburn was slower than growths recorded from any other Oklahoma reservoir of similar age and size (Table 12). These results agree with those of Finnell and Jenkins (1954) who found turbidities to retard growth of channel catfish uniformly in both small lakes and large lakes as well as in large reservoirs.

On the whole, however, the channel catfish seemed well adapted to Heyburn conditions. Growth rates compared more favorably with those from other waters than the bass and crappie growths, and the population structure was more normal as evidenced by a more even distribution among the different age and size groups.

Growth of flathead catfish at Heyburn compared favorably with growths in other Oklahoma reservoirs as recorded by McCoy (1955). However, McCoy's lakes were mostly older waters, while Heyburn is comparatively new. Average first-year growth at Heyburn was 4.9 inches, second year 11.0 inches, third-

Table 12. Channel catfish growths at Heyburn and Upper Spavinaw compared with growths made in other new Oklahoma reservoirs.¹

Name of reservoir	Condition	Size in acres	No. of fish	Dates collected	Average calculated total length in inches at end of year				
					1	2	3	4	5
Heyburn	Muddy	1,070	395	52-55	3.3	7.2	9.2	11.3	
Upper Spavinaw	Clear	3,192	5	54-55	6.6	18.8 ²			
Ft. Gibson	Clear	19,100	995	51-54	3.6	7.8	11.3	15.2	18.5
Tenkiller	Clear	12,500	171	1953	4.1	11.6	16.0	19.0	21.2
Canton	Inter-mediate	4,900	101	50-52	3.7	7.9	11.5	16.4	
Wister	Inter-mediate	4,000	20	50-53	5.1	11.7	16.1	20.6	20.9

¹ Comparative data from Finnell and Jenkins (1954).

² Represents a single specimen.

year 21.1, and fourth year 28.3 inches. Heyburn first-year growth was exceeded in only 7 of McCoy's 20 lakes, second-year growth in only five, third-year growth in two, and fourth-year growth in only one.

It seems evident that the flathead has a high tolerance if not an actual predilection for turbid conditions. McCoy observed that turbidity had little effect upon rate of growth in his studies, and Jenkins (1954) found flatheads to exhibit faster growths in the shallower, more turbid sections of Grand Lake than in the deeper, clearer waters. Heyburn flatheads certainly exhibited the most favorable growth of any species studied. In addition, it was relatively abundant, ranking 5th by weight, in rotenone collections; and all age and size groups were well represented in the population.

It is expected that the channel and flathead catfishes will provide the best future fishing opportunities at Heyburn. Since it is extremely doubtful

that any of the scaled fishes could ever be important in the Heyburn fishery, future management would do well to concentrate on catfish production.

Total Population Estimates

On the basis of rotenone samples, the standing crop of fish per acre at Heyburn was considerably less than that at Upper Spavinaw, and far below that for other Oklahoma reservoirs. Six coves, totalling 12.8 acres, were rotenoned at Heyburn in 1954, and an additional 3 coves, totalling 3.7 acres, were treated in 1955. One large cove of 10.0 acres was treated at Upper Spavinaw in 1955. All coves were closed off with nets to minimize movement by fish in or out of the sample areas. The data for 1955 for both reservoirs (Table 13) were based on complete recoveries of all but the smallest fishes. These small fishes were relatively scarce at Heyburn, but the fry of sunfishes, brook silversides, and fingerling bass, were extremely abundant at Upper Spavinaw, and their weights were estimated. For 1954, however, the Heyburn data are less complete since recoveries from three of the areas treated included only those fish which surfaced the first day. Should the total average recovery of 55.5 pounds per acre be doubled, the adjusted figure of 111.0 pounds is believed to represent the maximum possible poundage from these areas. Both this yield, and the yield of 117 pounds per acre from Heyburn in 1955 are well below the yield of 177 pounds per acre from Upper Spavinaw, and much below the averages recorded from similar experiments in other Oklahoma reservoirs. Thompson (1950) treated 8 areas, totaling 15.75 acres of clear Grand Lake (46,300 acres), and recovered an average of 623 pounds per acre. Jackson (1955) treated 8 acres of the clear Lower Spavinaw Reservoir (1,637 acres) and recovered an average of 540.6 pounds per acre. From the turbid Claremore City Lake (470 acres), Jenkins (1949) recovered an average of 236.4 pounds per acre from a treatment

of 3.5 acres.

Abundances of the various species in the rotenone returns from Heyburn and Upper Spavinaw are shown in Table 13. In summary, the outstanding differences were these.

1. In clear Upper Spavinaw, the gizzard shad represented 73.7 percent of the total weight of fishes, followed in order by bluegills (6.1 percent), largemouth bass (5.7 percent), carp (3.8 percent), with the channel and flathead catfishes of no significance (both representing less than 0.01 percent of the total weight of fishes).
2. In muddy Heyburn, shad ranked only fourth in 1955 (eighth in 1954), with carp first (23.7 percent), channel catfish second (16.8 percent), river carpsucker third (16.0 percent), flathead catfish fifth, bass sixth, and bluegills eleventh.
3. The ratio of the forage fishes (shad, minnows and the small sunfishes) to the predaceous bass and crappie was approximately 1 to 1 at Heyburn and approximately 13 to 1 at Upper Spavinaw. While the 13 to 1 ratio is somewhat higher than is generally believed desirable, it is of the order necessary to maintain a satisfactory sport fishery such as Upper Spavinaw now supports.
4. In Heyburn the combined weight of the rough fishes (carp, river carpsuckers, and the two species of bullheads) represented 42.4 percent of the population by weight, as compared with a total of 7.0 percent for the carp, bullheads, and the 5 species of suckers present at Upper Spavinaw.

On the basis of supplementary sampling data, the proportions of various species in Heyburn rotenone samples are believed to reflect accurately the true

Table 13. Pounds per acre and percentage composition from recoveries following rotenone treatment of 6 areas totalling 12.8 acres at Heyburn in 1954, of 3 areas totalling 3.7 acres at Heyburn in 1955, and one area of 10 acres at Upper Spavinaw in 1955.

Species	Average pounds per acre and percent (in parentheses) of total weight of fishes recovered		
	Heyburn		Upper Spavinaw
	1954	1955	1955
Gizzard shad	2.39 (4.3)	12.39 (10.6)	130.89 (73.7)
Largemouth bass	10.90 (19.6)	10.9 (9.3)	10.10 (5.7)
Smallmouth bass	... ..	... ..	1.97 (1.1)
White crappie	3.80 (6.8)	7.37 (6.3)	0.004 ...
Black crappie	0.09 (0.2)	... ..	0.02 ...
Bluegill	0.56 (1.0)	1.40 (1.2)	10.83 (6.1)
Green sunfish	0.70 (1.3)	1.85 (1.6)	5.13 (2.8)
Orangespotted sunfish	0.14 (0.3)	1.85 (1.6)	... ..
Longear sunfish	... ..	... ..	5.67 (3.2)
Redear sunfish	... ..	0.21 (0.2)	... ..
Warmouth bass	... ..	... ..	0.33 (0.2)
Rock bass	... ..	... ..	... ..
Channel catfish	6.75 (12.1)	19.69 (16.8)	0.05 (0.0)
Flathead catfish	6.46 (11.7)	11.36 (9.7)	0.03 (0.0)
Black bullhead	11.00 (19.8)	2.59 (2.2)	2.93 (1.7)
Yellow bullhead	0.09 (0.2)	0.53 (0.5)	0.16 (0.1)
Carp	5.71 (10.3)	27.81 (23.8)	6.68 (3.8)
River carpsucker	6.92 (12.4)	18.78 (16.0)	... ..
Black redborse	... ..	... ..	0.97 (0.6)
Hog sucker	... ..	... ..	0.58 (0.3)
White sucker	... ..	... ..	0.35 (0.2)
Spotted sucker	... ..	... ..	0.70 (0.4)
Misc. species	... ..	0.24 (0.2)	0.09 (0.1)
TOTALS	55.51 100.00	116.07 100.00	177.40 100.00

proportions of the population. However, both the black and white crappies, the largemouth bass, and the rock bass were known to be more abundant at Upper Spavinaw than indicated by the rotenone returns. Both crappies and the rock bass were commonly taken by wire traps in waters deeper than afforded by the rotenoned area, and a majority of the adult bass population appeared to be restricted to the open waters where they were often observed, as previously mentioned.

A most significant shortage noted in the Heyburn rotenone collections was that of the forage species, particularly the gizzard shad. The shad is the principal food of bass, crappies, and most other carnivorous forms in practically all large reservoirs where shad occur. They normally are present in enormous abundance, usually exceeding all other species in weight, as well as numbers. In the previously mentioned rotenone collections made at Grand Lake, Lower Spavinaw, and Claremore City Lake, shad made up about 66, 78 and 52 percent, respectively, of the total weight of all fishes and represented 73.7 percent of the total weight in the Upper Spavinaw sample.

In the Heyburn sample shad represented 4.3 percent of the total weight of all fish recovered in 1954 and 10.6 percent in 1955. Minnows and the common sunfishes also were scarce. All sunfishes represented less than 3 percent of the total weight of fishes.

The low population figures indicate that some strong limiting factor was in operation. The plankton feeders were certainly limited by the low level of plankton production, as will be discussed later. Carnivorous forms were just as certainly limited by the scarcity of these forage species upon which they are dependent for food. It also seems evident that reproduction of all species, with the exception of the catfishes, was limited to some degree by the high

rate of siltation, and associated turbidity.

Plankton Production

One of the most marked contrasts between the clear and turbid reservoirs was in volume of plankton production. Samples were taken at 15-foot intervals once each second or third week through both summers. The samples obtained from Upper Spavinaw were not unusually rich for Oklahoma reservoirs, a fact which further emphasizes Heyburn's deficiency. In 1954, the average volume (0.0085 milliliters per liter) of net plankton from the surface waters of Upper Spavinaw was 13.5 times greater than the average (0.0006) from Heyburn. Differences at both the 15- and 30-foot depths were similar, and the average volume from the 60-foot depth at Upper Spavinaw was greater than the combined total from the surface, 15-foot, and 30-foot depths at Heyburn. The contrast was less marked in 1955, the surface samples from Upper Spavinaw having approximately three times the volume of samples from Heyburn surface waters, and the 15- and 30-foot depths only approximately twice as great.

Fishing Success

Fishing at the two reservoirs differed distinctly in quantity and quality, as well as in the methods used. Heyburn received quite heavy use from picnickers and boating enthusiasts but very little fishing. It provides neither the natural beauty nor the fishing opportunities to attract the vacation angler and is utilized chiefly by local residents who fished the creeks with pole and line before the dam was constructed and who still employ much the same methods. Bait casting for bass was occasionally rewarding in the upper creeks when the streams were low and relatively clear, but bait fishing with cane poles, bank and trotlines predominated.

In sharp contrast, Upper Spavinaw combines grand scenic values with excellent fishing opportunities. Most anglers use boats and motors and cast for bass, although bait fishing for bass and crappies is popular. Trotlining is rare since the catfish population has not yet developed.

Creel census data show that from 3 to 4 times as many fish were removed from Upper Spavinaw than from Heyburn for the same unit of effort. Records taken by the City of Tulsa for the period September 1, 1954, through August, 1955, reveal the average catch per fisherman hour to have been 0.94 legal fish, of which 54.4 percent were largemouth bass, 30.5 percent crappie (black and white combined), the remainder consisting principally of smallmouth bass, miscellaneous sunfishes and black bullheads. The Heyburn catch during the summer of 1954, as recorded by the writer, was at the rate of 0.12 fish per fisherman hour, or approximately one fish for every 8 1/3 hours fished. The catch during September and October, 1954, as recorded by a local resident employed for the purpose, was at the rate of 0.40 fish per fisherman-hour. Combining the records for the two periods, the average catch was at the rate of 0.25 fish per fisherman-hour, consisting of approximately 45 percent crappie, 35 percent largemouth bass, 15 percent channel catfish, 3 percent bullheads, 1 percent flathead catfish, and 1 percent mixed sunfishes. These figures do not include trot-line fishing, however. From June through October of 1954, a total of 1,663.5 hours of trot-line fishing was recorded. This represents the total hours when baited lines were in the water. The catch consisted of 195 fish (155 channel catfish, 36 flatheads, and 4 bullheads), representing 0.12 fish per trot-line hour.

No creel census seemed justified at Heyburn in 1955 due to the extremely light fishing pressure. Often several consecutive days were spent on the lake

without encountering a single fishing boat, while anglers were always in evidence at Upper Spavinaw.

The census figures above are not believed to show as much difference as may really exist since the checks on Upper Spavinaw missed several periods when outstanding catches were made. For example, Mr. Sam Jackson, biologist for the City of Tulsa, estimated the largemouth bass catch by fishermen using rental boats in the period from mid-August to mid-September of 1953 to have been 14,000 legal-sized bass. His figures did not include bank fishing or private boat fishing. This was undoubtedly a peak period, but it is doubtful if 14,000 legal bass have been harvested from Heyburn since its impoundment.

DISCUSSION

Soil turbidity has been evaluated here as a principal limiting factor in growth and reproduction of fishes, food production and fishing success. Turbidity was studied because it is the most obvious and readily measured of the various effects of erosion. It should be mentioned, however, that turbidity may be only the visible evidence of other unmeasured factors which either contribute to, or are associated with, the undesirable conditions common to turbid waters. As observed by Irwin (1945), permanently turbid waters are invariably low in organic fertility. This presents the question as to whether turbidity is the cause or the result of the low fertility. In reality, it may be both. All waters are turbid following a large influx of erosion silt. The rate and degree of clearing depends upon the nature and size of the injected soil particles and the organic fertility of the water. Other conditions being equal, the most fertile water will clear more rapidly. This is due to a higher availability of positive ions capable of neutralizing

and precipitating the negatively charged soil particles (Irwin and Stevenson, 1951). However, if even the most fertile body of water is subjected to severe and continuous inflow of erosion silt the fertility will be dissipated and the turbidity may become permanent. Once established the turbidity excludes light necessary for the synthesis of organic matter and, in the natural course of events, the fertility may not be replenished to the point sufficient to cause precipitation of the soil particles responsible for the turbidity. Then only by artificial treatment, or the natural inundation or inflow of large quantities of organic matter, can the water be cleared sufficiently to once more enable the aquatic organisms to establish a cycle of organic matter synthesis and decomposition that can keep the water fertile -- and clear.

Siltation, or the settling and accumulation of transported materials is also common to highly turbid waters. The relationship of this blanketing action to bottom organisms, to fish reproduction, and to the biology of lake and stream bottoms is itself a fertile field for study. Siltation is also important, and costly, by its filling of reservoir basins and reducing the area of aquatic production. The siltation of Lake Mead provides the classic example. When constructed in 1936 it impounded 155,723 acres, and extended for a length of 115 miles. By 1950 siltation had reduced the length to 85 miles (Wallis, 1950), with enough silt added each year to cover to a depth of 5 inches an area equal to the maximum area of the lake (Moffett, 1943). The encroachment in ponds is also great. During the course of this investigation many pondowners were amazed to learn that ponds having 8-foot depths a few years before now measure only 3 to 4 feet. Complete loss of water in many Oklahoma ponds during the 1954 drouth was due to the fact that siltation had reduced their storage capacities. Such losses invariably occurred in the

muddiest ponds in locations subject to the most severe erosion.

SUMMARY

1. The results of a two-year study of the effects of turbidity on fish and fishing in Oklahoma ponds and large reservoirs is presented. The project was co-sponsored by the Outboard Boating Club of America, the Sport Fishing Institute, and the Oklahoma Game and Fish Department.
2. Pond work involved (1) a study of growth and reproduction of largemouth bass, bluegill and redear sunfish, and production of plankton in 33 experimentally stocked farm ponds of varying degrees of turbidity, and (2) a study of growth of largemouth bass, bluegill and channel catfish in artificially muddied hatchery ponds.
3. Large reservoir work involved a comparison of growth, reproduction and relative abundance of fishes, plankton production, and fishing success in a clear and a turbid reservoir, plus comparisons with other reservoir data.
4. At the end of two growing seasons, the average total weight of fish in clear farm ponds was approximately 1.7 times greater than in ponds of intermediate turbidity and approximately 5.5 times greater than in muddy ponds. Differences were due to faster growths by all species and to greater reproduction in clear ponds, particularly by bluegills and redear sunfish.
5. Of the 3 species used in farm ponds, largemouth bass were most affected by turbidity in both growth and reproduction. Redear sunfish appeared less retarded in growth than did bluegills during the first year, but the two sunfishes appeared equally restricted in both growth and

reproduction during the second year.

6. Average volume of net plankton in surface waters of clear ponds during the 1954 growing season was 8 times greater than in ponds having intermediate turbidities; 12.8 times greater than in the most turbid ponds.
7. In hatchery ponds, high turbidities reduced growth and total yield of bass and bluegills but increased channel catfish production. Individual catfish grew faster in clear ponds, but muddy ponds yielded much greater total weights of channel catfish than either clear or intermediate ponds. This was due to a higher rate of survival.
8. The presence of carp caused reduced growth of bass and bluegills but ponds with carp produced greater yields of channel catfish and young bluegills than ponds without carp.
9. Sodium silicate proved effective in sustaining hatchery pond turbidities when introduced in suspension with finely divided clay.
- 10/, Growths of largemouth bass, white crappies, and channel catfish were much slower in ^{the reservoir} turbid Heyburn than in clear Upper-Spavinaw Reservoir, as well as in all other Oklahoma reservoirs of similar age and size.
- 11/2. Growth of flathead catfish was the most favorable of any Heyburn ^{in the turbid reservoir} species studied, and ~~it~~ ^{the flathead catfish} is apparently well adapted to ^a the turbid environment.
- 12/3. The number of species, as well as individuals, of all scaled fishes was low in ^{the} turbid Heyburn reservoir, apparently due to a lack of successful reproduction in the turbid and heavily silted waters and due to competition from the better adapted catfishes.

13.4 The extreme scarcity of forage species, particularly gizzard shad, limited growth and development of bass, crappies, and other carnivorous species at Heyburn *in the turbid reservoir.*

14.5 Heyburn largemouth bass and white crappie populations *in the turbid reservoir* exhibited unusual dominance by older individuals. This seemed to be due to successively smaller year classes as a result of increasing turbidities.

15.6 In 1954, the average volume of net plankton in surface waters was *the clear reservoir* 13.8 times greater *the turbid reservoir* in Upper Spavinaw than in Heyburn, and average volume from the 60-foot depth at the clear reservoir was greater than the combined total from surface, 15-foot depth, and 30-foot depth in the muddy reservoir. This contrast was less marked in 1955, possibly due to somewhat lower average turbidities at Heyburn. *in the muddy reservoir.*

16.7 The clear reservoir attracted more anglers, yielded greater returns per unit of fishing effort, as well as more desirable species, and was immeasurably more appealing in the aesthetic sense.

BIBLIOGRAPHY

- Aldrich, A. D., 1949. Fish management in Oklahoma farm ponds. Okla. Game and Fish Dept., Special Publication: 19 pp.
- Bennett, George W., David H. Thompson and Sam A. Parr, 1940. Lake management reports. 4. A second year of fisheries investigations at Fork Lake, 1939. Ill. Nat. Hist. Surv. Biol. Notes 14, 24 pp.
- Bennett, George W., 1943. Management of small artificial lakes, a summary of fisheries investigations, 1938-1942. Ill. Nat. Hist. Surv. Bull. 22(3): 357-76.
- Berner, Lester M., 1951. Limnology of the lower Missouri River. Ecology 32: 1-12.
- Chandler, David C., 1940. Limnological studies of western Lake Erie. I. Plankton and certain physical-chemical data of the Bass Islands region, from September, 1938, to November, 1939. Ohio Jour. Sci., 40: 291-336.
- , 1942a. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecology 23: 41-52.
- , 1942b. Limnological studies of western Lake Erie. III. Phytoplankton and physical-chemical data from November, 1939, to November, 1940. Ohio Jour. Sci. 42: 24-44.
- , 1944. Limnological studies of western Lake Erie. IV. Relation of limnological and climatic factors to the phytoplankton of 1941. Trans. Amer. Micro. Soc. 63: 203-236.
- Chandler, David C. and Owen B. Weeks, 1945. Limnological studies of western Lake Erie. V. Relation of limnological and meteorological conditions to the production of phytoplankton in 1942. Ecol. Monographs, 15: 435-456.
- ✓ Claffey, Francis Joseph, 1955. The productivity of Oklahoma waters with special reference to relationships between turbidities from soil, light penetration, and the populations of plankton. Thesis, Oklahoma A. and M. College, 102 pp.
- ✓ Doan, Kenneth H., 1941. Relation of sauger catch to turbidity in western Lake Erie. Ohio Jour. Sci., 41: 449-452.
- , 1942. Some meteorological and limnological conditions as factors in the abundance of certain fishes in Lake Erie. Ecol. Monographs, 12: 293-314.
- Elder, David E. and William M. Lewis, 1955. An investigation and comparison of the fish populations of two farm ponds. Amer. Mid. Nat. 53 (2): 390-5, Apr. 55.

- Ellis, M. M., 1931. A survey of the conditions affecting fisheries in the upper Mississippi River. U. S. Bur. Fish., Fishery Circular No. 5.
- , 1936. Erosion silt as a factor in aquatic environments. Ecology, 17: 29-42.
- , 1937. Detection and measurement of stream pollution. Bull. U. S. Bur. Fish., 48: 365-437.
- , 1940. Water conditions affecting aquatic life in Elephant Butte reservoir. U. S. Bur. Fish. 49: 257-304.
- , 1944. Water purity standards for fresh-water fishes. U. S. Fish and Wildlife Service, Special Scientific Report No. 2: 16 pp.
- Fessler, Floyd R., 1950. Fish populations in some Iowa farm ponds. Prog. Fish Cult. 12: (1) Jan., 1950.
- Finnell, Joe C., and Robert M. Jenkins. 1954. Growth of channel catfish in Oklahoma waters: 1954 revision. Okla. Fish. Research Lab. Rept. No. 41, 37 pp.
- Hall, Gordon E., 1952. Farm ponds for cattle or for fish? Okla. Game and Fish News, 8: (5): 4-6.
- Hall, Gordon E., Robert M. Jenkins and Joe C. Finnell, 1954. The influence of environmental conditions upon the growth of white crappie and black crappie in Oklahoma waters. Okla. Fish. Research Lab. Rept. No. 40, 56 pp.
- Hambric, Robert Noel, 1953. Some effects of turbidity on bottom fauna. Thesis, Okla. A. and M. College.
- Irwin, William Henry, 1945. Methods of precipitating colloidal soil particles from impounded waters of central Oklahoma. Bull. Okla. A. and M. College, 42: 16 pp.
- , 1948. The development and decline of southwestern lakes. Okla. Game and Fish News, 4, (7 and 8): 4-5.
- Irwin, William Henry, and James H. Stevenson, 1951. Physiochemical nature of clay turbidity with special reference to clarification and productivity of impounded waters. Bull. Okla. A. and M. College, 48: 54pp.
- Jackson, S. W., Jr., (In press). Rotenone survey of Black Hollow on Lower Spavinaw Lake (Oklahoma). Proc. Okla. Acad. Sci. 35 (1954).
- Jenkins, Robert M., 1951. A fish population study of Claremore City Lake. Proc. Okla. Acad. Sci., 30 (1949).

- , 1953. Growth histories of the principal fishes in Grand Lake (O' the Cherokees), Oklahoma, through thirteen years of impoundment. Okla. Fish. Research Lab. Rept. No. 34, 87 pp.
- Jenkins, Robert M. and Gordon E. Hall, 1953. The influence of size, age and condition of waters upon the growth of largemouth bass in Oklahoma. Okla. Fish. Research Lab. Rept. No. 30, 44 pp.
- Jenkins, Robert M., 1954. Growth of the flathead catfish, Pilodictis olivaris, in Grand Lake (Lake O' the Cherokees), Oklahoma. Proc. Okla. Acad. Sci. 33 (1952): 11-20.
- Lagler, K. F., and W. E. Ricker, 1942. Biological fisheries investigations of Fouts Pond, Gibson County, Indiana. Invest. Ind. Lakes and Streams, 2: 47-72.
- Langlois, Thomas H., 1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water areas. Trans. Sixth N. Am. Wildlife Conf., 1941: 189-201.
- McCoy, H. A., 1955. The rate of growth of flathead catfish in 21 Oklahoma lakes. Proc. Okla. Acad. Sci. 34 (1953).
- Meyer, Bernard S. and Albert C. Heritage, 1941. Effect of turbidity and depth of immersion on apparent photosynthesis in Ceratophyllum demersum. Ecology, 22: 17-22.
- Meyer, Bernard S., Frank H. Bell, Lawrence C. Thompson, and Edythe I. Clay, 1943. Effect of depth of immersion on apparent photosynthesis in submerged vascular aquatics. Ecology, 24: 393-399.
- Moen, Tom, 1947. Why rough fish removal? Iowa Conservationist, 6: 153, 156-157.
- Moffett, James W., 1943. A preliminary report on the fishery of Lake Mead. Trans. Eighth North Am. Wildl. Conf., 1943: 179-186.
- Moore, George A., 1944. Notes on the early life history of Notropis girardi. Copeia, 1944: 209-213.
- , 1950. The cutaneous sense organs of barbled minnows adapted to life in the muddy waters of the great plains region. Trans. Am. Micr. Soc., 69: 69-95.
- Munns, Edward N., 1948. Our forests and watersheds. The Scientific Monthly, 67: 346-354.
- Schnabel, Z. E., 1938. The estimation of the total fish population in a lake. Am. Math. Monthly 45 (6): 348-352.

- Schneberger, Edward, and Minna E. Jewell, 1928. Factors affecting pond fish production. Kans. Forestry, Fish and Game Comm., Bull. No. 9, 5-14.
- Shapavalov, Leo, 1937. Experiments in hatching steelhead eggs in gravel. Calif. Fish and Game 23: 208-214.
- Shaw, Paul A., and John A. Maga, 1943. The effect of mining silt on yield of fry from salmon spawning grounds. Calif. Fish and Game, 29: 29-41.
- Smith, Osgood R., 1940. Placer mining silt and its relation to salmon and trout on the Pacific Coast. Trans. Am. Fish. Soc., 1939: 225-230.
- Sumner, Francis H. and Osgood R. Smith, 1940. Hydraulic mining and debris dams in relation to fish life in the American and Yuba Rivers of California. Calif. Fish and Game, 26: 2-22.
- Thompson, W. H., 1950. Investigation of the fisheries resources of Grand Lake. Fish. Mgt. Rept. No. 18, Okla. Fish. Research Lab., February, 1950.
- Van Oosten, John, 1948. Turbidity as a factor in the decline of Great Lakes fishes with special reference to Lake Erie. Trans. Am. Fish. Soc., 75, 281-322.
- Wallen, I. Eugene, 1951. The direct effect of turbidity on fishes. Bull. Okla. A. and M. College, 48: 27 pp.
- Wallis, Orthello, L., 1951. The status of the fish fauna of the Lake Mead National Recreational area, Arizona-Nevada. Trans. Am. Fish. Soc. 80: (1950)
- Ward, Henry Baldwin, 1938. Placer mining on the Rogue River, Oregon, in its relation to the fish and fishing in that stream. Oregon Dept. Geol. and Min. Indust., Bull. No. 10: 4-25.
- Welch, Paul S., 1935. Limnology. McGraw-Hill Book Co., New York, 471 pp.