Soil Turbidity, Light Penetration and Plankton Populations in Oklahoma Ponds and Lakes[1]

W. H. IRWIN[2], Oklahoma State University

and

FRANCIS J. CLAFFEY, State University College at Brockport, New York

The purpose of this study was to compare Oklahoma ponds and lakes with regard to the effects of soil turbidity on productivity and to measure penetration of various wave lengths of the visible spectrum through waters of different turbidities. The relationship between soil turbidity, light penetration and plankton abundance was considered.

The study was started in July 1953 and concluded in October 1954. Twenty farm ponds (10 clear and 10 muddy) and 20 lakes (10 clear and 10 with muddy waters) were studied to determine similarity between larger and smaller impoundments with regard to turbidity and plankton production.

Net plankton organisms were classified as either phyto- or zooplankton. The term cocci was used for all spherical forms, bacilli for all rod-shaped forms, and spirilla to include all spiral forms.

Turbidities recorded from farm ponds and lakes were placed in three turbidity ranges: 1) $<$25 ppm, 2) 25-50 ppm and 3) 51-350 ppm. The numbers of organisms were averaged and listed with the turbidity range in which they were found.

Chandler (1944); Chandler and Weeks (1945); Leonard (1950); Prescott (1939); and Silvey and Harris (1947) reported that increased soil turbidity tends to decrease phytoplankton production.

Irwin (1948); Ellis (1936); and Coker (1954) offered evidence that soil turbidities screen much of the light from natural water.

Ponds and Lakes Studied

Twenty farm ponds ranging in surface area from 0.4 - 2.2 acres, and 20 lakes ranging from 9.0 - 43,500 acres were selected for study. The areas were determined at spillway levels.

The 10 clear and 10 turbid farm ponds selected are located in Payne County, Oklahoma. Pairs of contrasting clear and turbid ponds were selected on the bases of similarities in surface area, watershed and locality.

An extended drought brought water levels in all impoundments in the region far below normal. The surface acreage at spillway level was determined for each of the farm ponds. In order to show pond shrinkage, the area covered by water in November was measured in 6 of the ponds. The shrinkage was found to be about 50% of the area covered at spillway level.

The lakes studied (Table I) are located in the northern two-thirds of Oklahoma. The lakes were selected on the bases of turbidity of the water and availability to the public and to the investigator.

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[1]Contribution No. 254 from the Department of Zoology, Oklahoma State University.
[2]Currently with the Federal Water Pollution Control Administration, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

TABLE I. THE 20 LAKES SELECTED.

Name of Lake	Location	Date Constructed	No. of Acres Impounded
Clear Water Lakes			
Canton	North Canadian River near Canton	1949	4.900
Fort Gibson	Neosho River near Fort Gibson	1951	19,000
Grand	Neosho River near Miami	1940	46,300
Hulah	Caney River near Bartlesville	1950	3,200
Lower Spavinaw	Near Spavinaw	1923	1,638
Pawhuska	Near Pawhuska	1937	95
Ponca	Vicinity of Ponca City	1935	805
Sanborn	Two miles north of Stillwater	1946	9
Shawnee	Near Shawnee	1935	1,336
Tenkiller	On Illinois River near Gore	1952	12,500
Turbid Water Lakes			
Boomer	North of Stillwater	1925	215
Carl Blackwell	Stillwater Creek west of Stillwater	1937	3,380
Claremore City	Near Claremore	1922	470
Cushing	Near Cushing	1928	440
Perry City	Near Perry	1937	400
Heyburn	On Polecat Creek near Sapulpa and Bristow	1950	1,070
Liberty	Three miles east of Guthrie	1946	201
Pawnee City	Vicinity of Pawnee	1933	257
Tecumseh City	Near Tecumseh	1929	127
Yost	Northeast of Stillwater	1912	27

METHODS

Turbidities were measured in ppm with a Jackson turbidimeter and visibility with a Secchi disk, using the standard method (Welch, 1948). Transmission of light through turbid water was measured by a Gaertner spectrophotometer in the optics laboratory of the Physics Department of Oklahoma State University. Turbid waters were brought to the laboratory where they were diluted with distilled water until the necessary turbidities were obtained. Each sample was read for turbidity, diluted, and re-read, because diluting the water with an equal volume of distilled water did not reduce the original turbidity exactly one-half. The measurements were recorded in percentages of transmission. Only the wavelengths within the visible spectra were measured. Four pairs of glass cells, 1, 2, 3 and 4 inches long, were made and used in the spectrophotometer to obtain percent of light transmission through various turbidities.

Net plankton samples were collected 6 times, 5 stations each from Village and Metzger Ponds and 1 station each from the other 18 farm ponds, during a 6-month period starting 16 April and ending 10 October 1954. Samples were taken from the surface waters and at each succeeding 5 ft of depth. Bottom samples were not taken in ponds that were less than 5 ft deep. Net plankton samples also were taken once from each of the 20 lakes at the surface and every 15 ft of succeedng depth, between 10 April and 1 August 1954. Since all collections were made between 7:30 a.m. and 12 noon, samples could not have been affected by those zooplankters that display diurnal migrations.

The examination of plankton involved a differential count and a volumetric measurement. Differential counts were made to determine the number of phytoplankters and zooplankters per liter of water using the standard method of Welch (1948). Volumetric measurements were secured by using the method of Leonard (1950).

Water samples for bacterial counts were collected 6 times at 5 stations each from Village and Metzger Ponds and 1 station from each of the other 18 farm ponds from 16 April to October 1954 and from each of the 20 lakes between 10 April and 1 August 1954, when the net plankton samples were collected. Water samples for bacterial counts were obtained from the 30 liters of water which had been strained through a Wisconsin plankton net in obtaining plankton samples. Water samples were placed in glass vials and stoppered. The vials previously had been washed clean with soap and water, and rinsed in boiling water. Bacterial counts were made immediately, or the water samples were packed in ice, brought to the laboratory and counted at once. A hemocytometer designed to count red blood cells (Stitt, Clough and Clough, 1943) was used to count cocci, bacilli, and spirilla. Since bacteria vary widely in their food, oxygen, pH, and temperature requirements, it would have been impossible to culture all of the indigenous bacteria of an impoundment on a single medium and at the same temperature. The plating method would at best be an inaccurate estimation of a bacterial population, since theoretically each colony in the plated medium would develop from a single bacterium. However, several bacteria may clump together to form a colony. The direct counting method used was quick and gave a more accurate estimation of bacterial numbers, in agreement with Bere (1933). The sample was agitated in the vial and in the pipette to insure uniform distribution. Counting the bacteria was done exactly as red blood cells are counted except that no dilution of the sample was made and bacteria were counted over the entire red-blood-cell field (25 squares). For each sample, three counts were made and averaged.

Since the counting field covered an area of 1 mm^2 and a depth of 0.1 mm, the volume of water in the counting field was 0.1 mm^3. The number of bacteria per liter was then computed.

Light Penetration in Turbid Waters

The percentages of the wavelengths (4500 to 7000 A) of visible light transmitted through 1 to 4 inches of water ranging in turbidity between 25 and 350 ppm (the range for pond waters) as measured with a spectrophotometer are shown in Table II. Readings of 0.0 percentage of light transmission mean that the amount of light was so reduced that it was not detectable by the human eye.

Red wavelengths (7000 A) had the greatest penetration. Transmission rapidly decreased as turbidity and depth increased. Water with a turbidity of 25 ppm permitted 24.9% of the original light of 7000 A to penetrate 4 inches. Water with a turbidity of 150 ppm permitted no light of any visible wavelength to pass through 3 inches.

Secchi disk readings in the clear ponds ranged from 14 to 72 inches. Readings in the turbid ponds ranged from 0.9 to 11 inches.

TABLE II. THE PENETRATION OF VISIBLE LIGHT THROUGH VARIOUS TURBIDITIES AND DEPTHS, EXPRESSED IN PERCENT OF LIGHT TRANSMISSION.

Wave-length (A)	1-inch glass cell	2-inch glass cell	3-inch glass cell	4-inch glass cell	turbidity ppm
4500	38.0	18.3	9.5	6.0	25
	16.0	5.5	2.7	1.6	50
	9.0	1.8	0.0	0.0	75
	3.5	0.0	0.0	0.0	100
	1.0	0.0	0.0	0.0	150
	1.0	0.0	0.0	0.0	200
	0.0	0.0	0.0	0.0	250
	0.0	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
5000	41.3	19.0	13.2	8.5	25
	19.0	8.4	4.1	2.0	50
	9.5	2.2	1,5	0.0	75
	6.0	0.8	0.0	0.0	100
	2.3	0.3	0.0	0.0	150
	1.7	0.0	0.0	0.0	200
	1.0	0.0	0.0	0.0	250
	0.8	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
5500	45.5	21.0	15.4	11.5	25
	21.0	11.0	5.6	2.6	50
	11.0	2.8	1.8	0.3	75
	7.0	1.3	0.5	0.0	100
	3.4	0.8	0.0	0.0	150
	2.5	0.4	0.0	0.0	200
	0.0	0.0	0.0	0.0	250
	0.0	0.0	0.0	0.0	300
	0.0	0.0	0.0	0.0	350
6000	48.2	24.0	19.3	16.0	25
	24.3	13.0	7.4	3.5	50
	13.0	3.8	2.4	1.5	75
	9.5	1.9	1.5	0.0	100
	4.5	1.3	0.0	0.0	150
	3.3	0.0	0.0	0.0	200
	2.5	0.5	0.0	0.0	250
	1.5	0.0	0.0	0.0	300
	0.5	0.0	0.0	0.0	350
6500	53.6	26.8	22.0	20.0	25
	27.8	15.1	9.3	5.0	50
	15.5	5.5	3.2	1.9	75
	11.0	2.7	2.3	Trace	100
	5.7	1.7	0.0	0.0	150
	4.1	1.5	0.0	0.0	200
	3.3	1.3	0.0	0.0	250
	1.9	0.0	0.0	0.0	300
	0.7	0.0	0.0	0.0	350
7000	58.0	39.2	28.0	24.9	25
	32.0	17.5	11.0	6.3	50
	19.0	7.2	4.1	2.4	75
	12.5	3.6	2.7	Trace	100
	7.0	2.3	0.0	0.0	150
	5.0	1.9	0.0	0.0	200
	3.9	1.5	0.0	0.0	250
	2.4	0.0	0.0	0.0	300
	1.0	0.0	0.0	0.0	350

Farm Pond Studies

Village Pond, consistently clear, and Metzger Pond, always turbid, were selected for an intensive study concerning the effects of turbidity on plankton production. Five stations in each of the above ponds were located in shallow and maximum depths. The numbers of phytoplankters, zooplankters, bacteria, and the volumes of net plankton in Village Pond everywhere were greater than those in Metzger Pond (Tables III and IV).

The numbers of organisms and the volumes of net plankton are related to turbidities of pond waters at the surface for those ponds in which both surface and bottom samples were taken and for the surface waters of all 20 ponds (Table V). The numbers of plankters and bacteria and the volumes of net plankton were greater in range 1, markedly smaller in range 2 and still smaller in range 3.

The numbers and volumes of plankters decreased between the surface and bottom waters in clear and turbid ponds. The numbers of cocci and bacilli were greater in the bottom than in the surface waters of clear ponds but the reverse was found in turbid ones. The numbers of spirilla were greater in the bottom than in the surface waters of both the clear and turbid ponds.

Lake Studies

Studies of the 20 lakes were conducted in a manner similar to that used on ponds, with only one series of records for each lake. The dates of data collection were rather widely separated because of the distance involved and the time available for field work. At each lake Secchi disk readings were taken and samples of water were collected for turbidity determinations. The volumes of net plankton were measured and the numbers of the several kinds of organisms, plankters and bacteria, were counted.

Secchi disk readings, in inches, ranged from 16 to 96 for clear lakes and from 2 to 9 for turbid ones. The turbidity in all lakes ranged from 25 to 255 ppm.

The numbers of phyto- and zooplankters, for the most part, decreased as turbidity increased. However, in bottom waters, zooplankters were present in equal numbers in turbidity ranges 2 and 3 and net plankton was present in greater volume in bottom waters of turbidity range 3 than in 2 (Table VI).

The numbers of bacteria in the samples are somewhat confusing, but were higher in clear than in turbid waters. In turbidity range 3 the numbers of bacteria exceeded those in range 2, except that cocci were present in slightly lower numbers at the surface in range 3 than in 2 (Table VI).

Although the pattern of abundance and distribution of organisms in the lakes was similar to that in ponds, the numbers of organisms per liter and volumes of net plankton in cc/liter were generally greater in ponds in all turbidity ranges.

Discussion

Analysis of the data presented shows certain specific conditions to exist during the time the collections were made. The numbers of phytoplankters, zooplankters, cocci, bacilli, spirilla, and the volumes of net plankton were greatest in waters with turbidities of 0-25 ppm. The numbers of all organisms were markedly smaller in the waters in the turbidity range of 25 - 50 ppm and still smaller in the turbidity range of 51 - 350 ppm. The greatest decline fell between the first two ranges.

TABLE III. COMPARATIVE AVERAGE NUMBERS OF ORGANISMS PER LITER (NET PLANKTON VOLUMES IN CC/LITER AT 5 STATIONS EACH OF A CLEAR (VILLAGE) AND A TURBID (METZGER) POND. NUMBERS OF BACTERIA IN MILLIONS.

	Village Pond 16 April—10 Oct. 1954 (<25 ppm)		Metzger Pond 26 April—10 Oct. 1954 (199.8 ppm)	
	Station 1		Station 1	
Plankton	Surface	Bottom	Surface	Bottom
Phytoplankton	41,500	16,900	1,400	200
Zooplankton	6,600	1,100	200	0
Net Plankton Volume	0.0299	0.0108	0.0012	0.0003
Cocci	27	39	5	2
Bacilli	59	167	16	9
Spirilla	4	15	5	9
	Station 2		Station 2	
	Surface	Bottom	Surface	Bottom
Phytoplankton	65,000	—	1,700	—
Zooplankton	12,700	—	300	—
Net Plankton Volume	0.0475	—	0.0014	—
Cocci	32	—	7	—
Bacilli	248	—	20	—
Spirilla	19	—	6	—
	Station 3		Station 3	
	Surface	Bottom	Surface	Bottom
Phtyoplankton	56,400	—	2,000	—
Zooplankton	10,600	—	300	—
Net Plankton Volume	0.0386	—	0.0015	—
Cocci	57	—	3	—
Bacilli	309	—	21	—
Spirilla	22	—	7	—
	Station 4		Station 4	
	Surface	Bottom	Surface	Bottom
Phytoplankton	55,700	—	1,000	—
Zooplankton	10,300	—	300	—
Net Plankton Volume	0.0442	—	0.0016	—
Cocci	50	—	5	—
Bacilli	236	—	18	—
Spirilla	22	—	9	—
	Station 5		Station 5	
	Surface	Bottom	Surface	Bottom
Phytoplankton	40,300	16,000	2,000	—
Zooplankton	7,100	1,200	200	—
Net Plankton Volume	0.0322	0.0112	0.0014	—
Cocci	26	42	5	—
Bacilli	97	128	25	—
Spirilla	7	18	9	—

TABLE IV. COMPARATIVE AVERAGE NUMBERS OF ORGANISMS PER LITER (NET PLANKTON VOLUMES IN CC/LITER) FROM 5 SURFACE SAMPLES EACH IN A CLEAR (VILLAGE) AND A TURBID (METZGER) POND. NUMBERS OF BACTERIA IN MILLIONS.

	Village Pond 16 April—10 Oct. 1954 (<25 ppm)	Metzger Pond 26 April—10 Oct. 1954 (199.8 ppm)
Plankton	Surface	Surface
Phytoplankton	51,900	1,800
Zooplankton	9,500	300
Net Plankton Volume	0.0385	0.0015
Cocci	39	5
Bacilli	190	20
Spirilla	13	7

The numbers of organisms and the volumes of net plankton per liter of water were generally greater for the farm ponds than for the lakes in all three turbidity ranges. In all waters, except Boomer Lake, the plankton crop was smaller in the higher turbidities.

The numbers and volumes of plankters were consistently smaller in the bottom than in the surface waters in clear and turbid lakes and ponds. The numbers of cocci and bacilli were greater in the bottom than in the surface waters of clear impoundments but the reverse was found in turbid ones. Spirilla differed in distribution in the surface and bottom waters in that their numbers were greater in the bottom than in the surface waters of both clear and the turbid impoundments.

Turbidity caused by silt must decrease the food production and affect the general economy of an impoundment. It would thus seem that light is a limiting factor for the productivity of both lakes and ponds. Chlorophyll-bearing organisms must have light to conduct photosynthesis. Non-chlorophyll-bearing organisms are dependent to a large extent on the chlorophyll-bearing ones (Welch, 1952). Without light, the chlorophyll-bearing plankters are reduced in numbers. Light was able to penetrate the waters with turbidities below 25 ppm to greater depths and thus could permit the development of a photosynthetic zone which could encompass most of the impoundment.

Village Pond, with an average turbidity of 25 ppm and with an average Secchi disk reading of 37 inches, had a high plankton productivity. It would seem that light was able to penetrate the water to the extent that it was nearly optimum for plankton production. A photosynthetic zone in Village Pond could have extended from the surface into the bottom waters. Metzger Pond, with an average turbidity of 199.8 ppm and with an average Secchi disk reading of 2.5 inches, was low in plankton. Light, measured in the laboratory, did not penetrate 3 inches of water with a turbidity of 150 ppm. It would seem that the photosynthetic zone would be restricted to a shallow layer at the surface and that light penetration was a limiting factor to productivity in Metzger Pond.

Fort Gibson Reservoir, with a turbidity of 25 ppm and a Secchi disk reading of 48 inches, had a large plankton crop. Heyburn Lake, with an average turbidity of 228 ppm and a Secchi disk reading of 2.0 inches, had a small plankton crop.

Birge and Juday (1930) found that, of all rays of the visible spectrum, red had the greatest penetration in stained waters and in waters with suspended matters. Similarly, we found that red penetrated deeper than

TABLE V. THE RELATIONSHIPS OF AVERAGE NUMBERS OF ORGANISMS PER LITER (NET PLANKTON VOLUMES IN CC/LITER) TO TURBIDITY OF SURFACE AND BOTTOM WATERS IN 20 PONDS. BACTERIA NUMBERS IN MILLIONS.

	Surface averages based on those ponds for which bottom samples were also taken				Surface averages based on twenty ponds		
	Water Level	Ranges of turbidity ppm			Ranges of turbidity ppm		
Plankton	Sampled	1) <25	2) 25-50	3) 51-350	1) <25	2) 25-50	3) 51-350
Phyto-plankton	Surface	26,800	5,200	2,600	28,600	6,000	2,600
	Bottom	15,000	1,100	300			
Zoo-plankton	Surface	3,300	1,100	400	3,500	1,200	400
	Bottom	1,900	200	0			
Net plankton volume	Surface	0.0164	0.0029	0.0017	0.0187	0.0037	0.0019
	Bottom	0.0111	0.0012	0.0004			
Cocci	Surface	19	10	5	19	12	5
	Bottom	29	20	2			
Bacilli	Surface	47	27	20	55	29	20
	Bottom	65	24	11			
Spirilla	Surface	5	5	4	6	4	6
	Bottom	17	8	7			

TABLE VI. THE RELATION OF ORGANISMS TO LAKE TURBIDITY RANGES IN AVERAGE NUMBERS PER LITER (NET PLANKTON VOLUMES IN CC/LITER). NUMBERS OF BACTERIA IN MILLIONS.

Plankton	Water Level Sampled	1) <25 ppm	2) 25-50 ppm	3) 51-255 ppm
Phytoplankton	Surface	14,900	3,200	2,200
	Bottom	4,700	600	300
Zooplankton	Surface	1,500	900	200
	Bottom	300	100	100
Net Plankton	Surface	0.0084	0.0024	0.0012
	Bottom	0.0061	0.0011	0.0030
Cocci	Surface	11	6	5
	Bottom	23	5	11
Bacilli	Surface	54	25	50
	Bottom	118	15	106
Spirilla	Surface	9	3	8
	Bottom	18	5	15

the other rays in turbid waters. We agree with Irwin and Stevenson (1951) that low turbidity, which allows light penetration, is essential for the synthesis of organic matter within a body of water.

The populations of plankton seem to have been affected by turbidity caused by soil particles in suspension in the water. The greatest effect of turbidity seems to have been the reduction of light penetration.

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