PLANKTON DISTRIBUTION IN RELATION TO WATER QUALITY AND AREA GEOLOGY AS INVESTIGATED IN NINE SOUTHEASTERN KANSAS LAKES

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INTRODUCTION

Problem Stated

> As for myself, I like only basic problems, and could characterize my own research by telling you that, when I settled in Woods Hole and took up fishing, I always used an enormous hook. I was convinced that I would catch nothing anyway, and I thought it much more exciting not to catch a big fish than not to catch a small one.
>
> Albert Szent-Gyorgi 1961

It seems reasonable that any variation in the habitat available to planktonic organisms among lakes of similar climate and morphometry will be due, chiefly, to the dissolved and suspended substances in the lake waters. That which is dissolved or suspended in a lake should depend directly upon the geological nature of the area in which the lake is located. Various lakes exhibit plankton populations which may be either quite similar or quite different. Since dissolved and suspended substances comprise a great portion of the habitat variability which occurs within the limnetic zone of a lake, and since these substances are present in their characteristic degree due to the geology of the lake's basin and catchment, lakes of similar geological makeup should be inhabited by similar plankton populations if suspended and dissolved materials have any influence on plankton distribution. However, it has been emphasized by Pennak (1949) that, with reference to small and medium sized lakes, there is no such thing as a "typical" lake. Each body of water has its own peculiar and variable plankton population. None-the-less all organisms have an optimal set of conditions under which they can survive, therefore, it seems reasonable to assume that given plankters would be more strongly associated with lakes in which these optimal conditions are met than in other lakes. On this assumption, the task was undertaken to determine whether or not there appeared to be any correlation between plankton types, water chemistry, and area geology in various lakes in Southeastern Kansas.

Lake Classification

In 1883, Marsh in Wisconsin, made one of the early attempts to recognize kinds or types of lakes on the basis of the organisms that lived in them. He considered the depth of the water as being one of the chief controls in the geographic distribution of copepods; and he suggested dividing lakes into shallow and deep types on the basis of their copepod faunas, with deep types being those over 40 meters in depth. In 1901 he revised this classification and changed the dividing depth between shallow and deep types to 30-35 meters (Frey, 1963).

The apparent likenesses and differences in the characteristics of different lakes tend to lead to attempts to build a classification system into which all lakes can be fitted. As yet, no such classification system has been developed which satisfies all variables, but a system first introduced by Thienamann in the early part of this century has come into common use. Taking into account the bottom oxygen supply and bottom fauna, he divided lakes into two types: oligotrophic and eutrophic. The fundamental distinction between the two types was on a proposed basis of available nutrient material, the oligotrophic type being poor and the eutrophic type being rich in these materials. Time has led to the use of these terms in relation to some of the following characteristics. Oligotrophic lakes are now characterized by: deep basins, a high thermocline, cold hypolimnion, low organic content, low or variable electrolytes, relatively poor calcium, phosphorous and nitrogen, high dissolved oxygen at all depths throughout the year, plankton composed of many species of which the Chlorophyceae are the dominant forms, few blooms, and a succession leading to the eutrophic type of lake; eutrophic lakes are characterized by: shallow basins, minimal or no deep cold water, variable but often high electrolytes, high calcium, phosphorous, and nitrogen, low dissolved oxygen in deeper stratified lakes of this type, abundant plankton of variable quality, frequent blooms, rich blue-green algae and diatom populations, and a succession into pond, swamp, or marsh. Certain European limnologists hold that average depth is the factor which determines whether a lake is eutrophic or oligotrophic, and they say that in oligotrophic lakes, the volume of the hypolimnion is greater than the volume of the epilimnion. The reverse would be true for eutrophic lakes (Welch, 1952).

Prescott (1960) stated that the terms "eutrophic" and "oligotrophic" refer to general productivity but that no positive specifications are given for them. He brought out that eutrophic lakes are those in which the pH is high and where available organic matter is rapidly reduced to liberate an abundance of vital mineral elements into the water. Oligotrophic lakes are those with low pH and low mineral nutrient content. He stated that oligotrophic lakes are spared algal blooms since they are low in electrolytes, nitrates, and phosphates. Such lakes, it is explained, also have a high Na + K / Ca + Mg ratio (3.2 or greater) and support a desmid and a planktonic chlorophycean flora. When the sodium to calcium ratio is low (1.1 or less) eutrophic conditions and a predominantly blue-green algal flora will exist.

Development of a trophic classification in terms of plankton types has been pursued mainly by European workers but as yet has had little application to the waters of North America. The usual scheme for distinguishing oligotrophic from eutrophic type lakes according to plankton type is given in Table I.

A mesotrophic lake is one which is intermediate between oligotrophic and eutrophic. From his work conducted in Western Canada, Rawson (1956) made a list of the dominant limnetic algae and characterized them as oligotrophic, mesotrophic, or eutrophic according to the lake types in which they were most commonly found. This represented a preliminary attempt in North America to construct a trophic classification in terms of algal types. The list is as follows:

Oligotrophic	*Asterionella formosa*
	Melosira islandica
	Tabellaria fenestrata
	Tabellaria flocculosa
	Dinobryon divergens
	Fragilaria capucina
	Stephanadiscus niagora
	Staurastrum spp.
	Melosira granulata

TABLE I. Plankton of oligotrophic and eutrophic lakes, after Rawson (1956).

Plankton Characteristic	Oligotrophic	Eutrophic
quantity	poor	rich
variety	many species	few species
distribution	to great depths	trophogenic layer thin
diurnal migration	extensive	limited
water blooms	very rare	frequent
characteristic algal groups and genera	Chlorophyceae Diatomaceae *Tabellaria* *Cyclotella* Chrysophyceae *Dinobryon*	Cyanophyceae *Aphanizomenon* *Anabaena* *Microcystis* Diatomaceae *Melosira* *Fragilaria* *Stephanodiscus* *Asterionella*

Mesotrophic	*Fragilaria crotonensis*
	Ceratium hirudinella
	Pediastrum borianum
	Pediastrum duplex
	Coelosphaerium naegelianum
	Anabaena spp.
	Aphanizomenon flos-aquaea
	Microcystis aeruginosa
Eutrophic	*Microcystis flos-aquaea*

The terms "soft water" or "hard water" are often heard in relation to lake water classification. The standard Wisconsin categories for these terms are as follows:

$< HCO_3^-$ 28 mg/l = soft

HCO_3^- 28-84 mg/l = medium hard

$> HCO_3^-$ 84 mg/l = hard

A useful addition to this classification is: $< HCO_3^-$ 10 mg/l = extremely soft (Brooks and Deevey, 1963).

Seasonal Variation

An important characteristic which must be taken into account in any thorough study of lake plankton is seasonal variation. This variation is striking in all lakes but it tends to follow a predictable pattern in each. Hutchinson (1944) divided phytoplankton variation in Linsley Pond, Connecticut, into four parts as follows: a spring maximum, a summer minimum, a late summer maximum, and an autumnal and winter period of relatively abundant plankton. In Linsley Pond, diatoms or blue-green algae dominated the spring maximum. Their decline was usually followed by a predominance of *Dinobryon* into the summer minimum, and finally an increase in the total plankton led to the development of great numbers of *Fragilaria crotonensis* and *Anabaena circinalis* during late summer. *Oscillatoria* became dominant before the fall overturn, and remained a common form through the winter along with *Scenedesmus* spp. and *Asterionella formosa*. Kozhova (1959) noted a seasonal variation in the algae of the shallower water in Lake Baikal. It began in spring with diatoms, changed to green algae during the early summer but ended the summer with blue-green algae, while in the fall diatoms again dominated. Whitford (1960) reported that in North Carolina, where spring and autumn are fairly long, it has been observed that in autumn there is a reversal of the expected spring flora with regards to species and their time of abundance. Late spring species came in earliest autumn and early spring species occurred in later autumn. In autumn there were fewer numbers of plankters, but the times of equal temperature were about the same. In spring, however, light intensities increased as temperatures became favorable, while in autumn the reverse was true. It was noted that if bright clear weather prevailed in autumn, the expected spring succession tended to be reversed during this time. For seven Colorado lakes, however, Pennak (1949) stated that no correlations were found between the seasonal occurrence and magnitude of plankton populations on the one hand and the annual cycles of temperature and dissolved oxygen on the other.

Lake to Lake Variation

It must be noted in beginning that a given species of planktonic algae may apparently be found most anywhere in the world where the proper conditions exist (Whitford, 1960). It would not be unlikely for a Southeastern Kansas form to be also common in a Central African lake. Yet, where world distribution does not appear limited in most cases, the kind of lake in any part of the world in which a given alga can be found does appear limited. What is it that is responsible for the occurrence of these organisms in a given lake? Let us look at some specific examples.

In 1904, West pointed out that the rich desmid floras which comprise a large number of species in this country were exclusively confined to the Western region in waters with a poverty of dissolved mineral salts. This region corresponded geographically with pre-Carboniferous rocks. This finding was an essential step forward in the study of plankton distribution, for it brought the distribution of a certain kind of plankton into line with the geological characteristics of the basins in which it was found (Fritsch, 1931).

In considering the ecological distribution of algae, Whitford (1960) pointed out that the effects of light, temperature, and water quality should be considered. In reference to water quality, Prescott (1939) related that it is well known, and an unfailing correlation, that great productivity of phytoplankton is provided by a high carbonate content and carbon dioxide reserve such as that found in the eutrophic type of lake. He also pointed out that lakes with much dissolved carbon dioxide and little dissolved oxygen contained filamentous and branched plants, while those low in carbon dioxide but high in dissolved oxygen contained unicellular and simple colonial forms. Blue-green algae, he noted, are found in waters of high conductivity and the ratio of Na + K / Ca + Mg has been considered important in determining plankton occurrence from lake to lake. When this ratio was low (1.1 or less), a diatom and Myxophycean flora dominated; but if it was high (3.2 or greater), a desmid and Chlorophycean flora dominated. He further noted that species which enter into "water bloom" associations thrived very successfully in warm water (25-30°C), particularly if there is an abundance of nitrogen compounds and carbon dioxide in reserve. It was noted by Whitford (1960) that many green algae do their best in high light intensities. The diatoms and Chrysophyceae seem to be more indifferent to light intensities but prefer cooler temperatures. Diatoms are apparently more abundant in northern lakes than in the lakes of lower latitudes.

In areas where disturbances occur due to algal blooms, the water is enriched in phosphates and nitrates. Disturbances usually occur in shallow water where recycling of nutrients is easy (Prescott, 1960). In 1925, Nauman stated that for the ponds of Aneboda, the poorer the water in mineral salts, the more the phytoplankton approximated that of lakes, while the richer the water, the more the plankton had the character typical of that of ponds. This seemed to indicate that it was richness in nutritive material that ruled out the typical pelagic plankton (Fritsch, 1931).

In reference to nine English meres studied, Gorham (1957) remarked that none of the analyses carried out gave any clue to the biological variation within the meres. While the general richness in mineral nutrients may be considered an important factor in producing frequent algal blooms, there existed local differences which bore no apparent relation to the chemistry of the mere waters as far as was known.

Some American phycologists believe that pH seems to be the best single indicator of algal flora type (Prescott, 1960). Below pH 7, lakes tend to contain many species but few numbers of phytoplankton. Above pH 7, numbers increase but kinds of species decrease.

METHODS AND MATERIALS

Twenty-five Southeastern Kansas lakes and ponds whose basins and catchments were situated in different geological formations were chosen for study. Nine of these were studied extensively for a one year period, samples being taken from the months of February, May, June, July, August, and October. The other 16 were investigated at the end of the one year period for comparative purposes. Since all of the bodies of water were of relatively small surface area, samples were taken from only a single station at each. This was usually located in the deep portion of the lake.

Water temperatures were taken with a glass mercury thermometer. With the thermometer in a shaded area, surface temperatures were taken directly from the surface water, and bottom temperatures were taken from bottom water directly upon transfer from a two liter Kemmerer water bottle to a one liter polyethylene bottle used for temporary storage of the water. Secchi disc readings were taken with an eight inch diameter secchi disc.

Samples for water quality analysis were taken from the surface waters with a Kemmerer water bottle, filtered through a 0.8 μ pore Millipore filter to remove suspended material, and then stored in one liter polyethylene bottles. From May 28 through August, 1966, filtering was carried out in the field. As this procedure also removed much of the bacteria, no further methods were used during this time to preserve water quality in the field. Chloroform was added to the later samples, which were not filtered, for this purpose. All samples were refrigerated upon return to the laboratory. On some dates, bottom water samples were also collected. These were filtered in the field and handled in a similar manner as were the surface samples.

Conductance, pH, and alkalinity were usually determined within a few days after return from the field. Other analyses were not conducted until later dates. The pH was determined with a Beckman Zeromatic II pH meter, and alkalinity was determined by titration with N/50 sulfuric acid to endpoints of pH 8.3 and 4.6. The results were converted to carbonate and bicarbonate alkalinity respectively according to Standard Methods (APHA, 1960). Resistance was measured with an Industrial Instruments Model RC-12 CIP conductivity bridge and converted to conductance in micromhos per centimeter at 25° C. Sodium, potassium, calcium, and magnesium estimates were made with a Coleman Model 21 flame photometer with a Model 6D Junior Spectrophotometer as the readout unit. Nitrate, nitrite, manganese, sulfate, and silica were determined according to the Hack Chemical Company procedures. The NitraVer II method was used for estimating nitrate, the NitraVer powder method for nitrite, the turbidimetric method for sulfate, and the manganese II powder method for manganese. Hack's molybdosilicate method for silica estimation was modified by dropping the last step to prevent interference which occurred as silica reagent 3 was added to the sample. The optical density was read at 410 mμ during the yellow phase, instead of at 690 mμ after addition of silica reagent 3 which produced a blue color phase. Orthophosphate, chloride, bromide, copper, and iron were determined according to the methods outlined in Standard Methods (APHA, 1960). The stannous chloride method was used for orthophosphate determination, the Mohr method for chloride, the cuperthol method for copper, and the phenanthroline method for iron. The method using phenol red and chloramine-T was used for bromide estimation. Dissolved oxygen determinations were conducted in the field according to the standard Winkler method. A Beckman model B spectrophotometer was used for all color analyses except that for sulfate. A Bausch and Lomb Spectronic 20 was used in this case.

Except where shore samples were taken, composite plankton samples were collected from the upper three meters of each lake. This was considered to be a reasonably representative sample of what would be present in the epilimnion. Using a two liter Kemmerer water bottle, four liters of water from each of the top three meters of the lake were strained through a number 20 mesh silk bolting cloth plankton net. The plankton was concentrated into a small vial attached to the end of the net. Formalin was used to preserve the sample.

Plankton identification and density estimations were made in the laboratory. From the concentration of twelve liters of lake water which was brought to a volume of 25 ml., a one-milliliter subsample was withdrawn and the organisms were counted under a binocular microscope at 23x. The results were then used to calculate the number of organisms per liter.

Plankton identifications were made using a monocular compound microscope with oil immersion and the taxonomic keys of Prescott (1962, 1964), Smith (1950), Tiffany and Britton (1952), and Pennak (1953).

With the aid of the Kansas State Teachers College Data Processing Lab, rank-difference correlations were determined for most of the parameters estimated in this study. Due to its great chemical difference in relation to the other lakes studied, the strip mine lake at the Sunflower Pits was excluded from these correlations.

RESULTS AND DISCUSSION

Geology of the Study Area

All of the lakes studied were located in the Pennsylvanian System of rock strata. The description of this system and the pertinent series and groups which compose the area in which these lakes lie is based on Moore, et. al. (1951). The Pennsylvanian System is a division of the late Paleozoic and is widely represented throughout the world. It is distinguished by the importance of its coal deposits and the characters of its large assemblage of fossilized marine invertebrates and varied land plants. It is one of the most important among outcropping strata of Kansas because of the economic value of its contained materials, and because of the prominent status of its rock succession as a standard of reference in studies of equivalent deposits in other parts of the continent.

As used here, the Pennsylvanian System is the upper part of what is referred to over much of the world as the Carboniferous System. The aggregate thickness of its exposed formations in Kansas is about 3,100 feet. The outcrops occur throughout the eastern quarter of the state. Three series within the Pennsylvanian System were concerned with in this study. They were the Virgilian, the Missourian, and the Desmoinesian Series.

The Virgilian Series comprises the youngest of the Pennsylvanian rocks of the midcontinent. The thickness is commonly about 1,200 feet. In this study it included the Shawnee and Douglas groups. The Shawnee group comprises four limestone formations and three shale formations.

Its average thickness is about 325 feet. One farm pond in westcentral Woodson County was studied in this group. The Douglas group is composed chiefly of clastic rock, shale, and sandstone. Limestone, coal, and conglomerate are quantitatively of minor importance in this group. Three lakes and two farm ponds from this group were studied.

The Missourian Series is composed of Upper Pennsylvanian rocks which in Kansas comprise a thickness of about 700 feet. Two groups within this series were of concern in this study, the Lansing and the Kansas City. The Lansing group includes a rather compact assemblage of two limestones and a thin shale formation. It averages about 85 feet thick. Two lakes from this group were studied. The Kansas City group is composed of limestone, shale, and local sandstone. It comprises a thickness of about 350 feet. Four lakes and one farm pond from this group were studied.

The Desmoinesian Series forms the lowermost major division of the Pennsylvanian rocks at outcrops in Kansas. Named from exposures in Central Iowa, it comprises the upper part of the middle Pennsylvanian. The Marmaton and Cherokee groups within this series were important in this study. The Marmaton group forms the Upper Desmoinesian beds in Kansas and is composed of limestone, shale, and some sandstone. The group is about 250 feet thick. Six lakes and three farm ponds located in this group were studied. The Cherokee group is composed mainly of clastic rock with light and dark-colored shale predominating. Much sandstone and shale exist in this group and also the most important coal beds of the state. The amount of limestone present is small. The

Cherokee group is about 400 to 550 feet thick. Two strip mine lakes located in this group were studied.

General Description of the Lakes

Table II contains various climatic and geologic information concerning the nine lakes studied over the period from May 28, 1966 to May 4, 1967. These are the lakes most thoroughly described in this report. Seven of these lakes have surface areas of approximately 100 acres, while two of them are small strip mine lakes of only a few acres each. These lakes were dispersed throughout five geologic groups and ranged in elevation between about 800 and 950 feet above sea level (Gannett, 1906). The average rainfall at the different lakes varies from 36 to 41 inches per year, and the mean annual temperatures range from 56.2 to 57° F (United States Dept. of Agriculture, 1946a, 1946b, 1948, 1950, 1952, 1956). The climatic condition for all nine lakes are, in general, similar. Three of the 100 acre lakes have been drained at one time or another for management purposes, but were then refilled. The oldest of the lakes, Crawford County State Lake #2, was impounded in 1926; the youngest, Bourbon County State Lake, was impounded in 1957. Neither of these lakes were ever drained (Schoonover, 1966). It should be noted that the soils from the drainages of the various lakes are derived from three principal parent materials; these are sandstone, limestone, and shale.

In addition to these lakes, sixteen other lakes and ponds with parent soil materials of sandstone, limestone, and shale were visited on May 3 and 4, 1967. These included four lakes of the 100 acre type,

TABLE II. Some statistics for the nine study lakes.

Lake	Location	Geologic Group	Approx. Elevation (feet)	Year Impounded	Dates Drained and Reimpounded	Average Annual Rain (inches)	Mean Annual Air Temp. (oC)
Montgomery County State Lake	Central Montgomery County, south of Independence, Sec. 19 & 20, T33S, R16E.	Kansas City	800	1953		37.3	57
Woodson County State Lake	Southeastern Woodson County. Just east of Toronto. Sec. 11 & 14, T26S, R14E.	Douglas	900	1933	1949	36	56.2
Bourbon County State Lake	Southwest Bourbon County, north of Porterville. Sec. 12 & 14, T26S, R21E.	Kansas City	900	1957		41	--
Bourbon County Lake	Southwest Bourbon County, northeast of Haitville. Sec. 26, T26S, R23E.	Marmaton	850	1935	1951	41	--
Wilson County State Lake	Northcentral Wilson County, near Buffalo. Sec. 17, T27S, R16E.	Lansing	900	1955		37.2	57
Crawford County State Lake #2	Northcentral Crawford County, east of Farlington. Sec. 5, T28S, R24E.	Marmaton	950	1935		41	57
Neosho County State Lake	Southwest Neosho County, northeast of Parsons. Sec. 22, T30S, R20E.	Marmaton	910	1926	1962	38.7	56.3
Crawford County State Lake #1	Eastcentral Crawford County, north of Frontenac, Sec. 8, T30S, R25E.	Cherokee	925	1926		41	57
Strip Mine Lake in the Sunflower Pits	Northeast Cherokee County, 3 miles south of U.S. Highway 160 just east of Lightning Creek.	Cherokee	--	--		--	--

TABLE II. (Contimued)

Lake	Surface Area (Acres)	Depth at Sampling Station (Meters)	Capacity (Acre-feet)	Drainage Area (Acres)	Vegetation of Drainage	Dominant* Parent Soil Materials of Drainage
Montgomery State Lake	105[a]	8	--	--	Grassland[c] and some woodland	Ss
Woodson County State Lake	179[a]	15	1797[b]	4200[b]	Woodland[c] and grassland	Ss, L
Bourbon County State Lake	103[a]	15	--	--	Grassland[c] and some woodland	L
Bourbon County Lake	100	8	--	--	Grassland[c] and some cultivated land	L
Wilson County State Lake	119[a]	15	--	--	Grassland[c] and some cultivated land	L
Crawford County State Lake #2	150[a]	15	3474[b]	3500[b]	Woodland and grassland	L, Sh
Neosho County State Lake	92[a]	6	756[b]	2200[b]	Grassland[c] with some woodland and cultivated land	Sh, L
Crawford County State Lake #1	ca. 5	3.5	--	--	Woodland	Shaly
Strip Mine Lake at the Sunflower Pits	ca. 5	4	--	--	Largely barren, typical first stage strip mine succession	Shaly

[a]Breukelman (1964)

[b]Andrews and Breukelman (1952)

[c]United States Dept. of Agriculture (1946a, 1946b, 1950, 1952, 1956)

*Ss = Sandstone and interbedded sandy shale, L = Limestone and interbedded limy shale, and Sh = Heavy shale and shaly clay.

eight ponds, seven of which were farm ponds, and four bodies of water intermediate in size between these two types. The purpose of collecting from these additional bodies of water was to see if the relationships that seemed to exist in the original nine lakes studied would hold true for a larger sample. Silica was the only chemical analyzed, but most of the plankton types were enumerated. Information from this collection will be discussed only as it may alter the conclusions which were drawn from the study of the original nine lakes.

Physical-Chemical Conditions

Light and temperature are two parameters which have already been mentioned as playing roles in the lives of plankton organisms. Water quality has also been mentioned. In this section, some of these parameters will be discussed in detail in relation to their existence in the nine lakes studied. Tables III and IV display some of the pertinent data.

Nitrogen, phosphorous, potassium, magnesium, iron, calcium, zink, manganese, and copper are necessary for the growth of all algae. Silicon is necessary for diatoms and sodium for some species of Anabaena (Krauss, 1958). Carbon dioxide, boron, chlorine, molybdenum, cobalt, vanadium, and sulfur compounds are also necessary, but all of these are not needed by all algae (Hutchinson, 1961).

It can be seen from the secchi disc averages in Table III that all of these lakes have relatively clear water with the exception of Neosho County State Lake. Past Kansas Forestry, Fish and Game Commission records obtained from Schoonover (1966) show that water transparencies

TABLE III. Some average physical-chemical conditions in the nine lakes studied. All measurements are in ppm unless otherwise stated.

Lake	Parent* Soil Material	Sicchi Disc. (Meters)	Range pH	$HCO_3^-/CO_3^=$	Sp. Cond. umhos/cm^2	PO_4	NO_3	NO_2	SO_4
Montgomery County State Lake	Ss	1.1	8.05	91/0.0	228	0.023	0.20	0.0029	9.3
Woodson County State Lake	Ss, L	2.1	7.8-8.25	82.8/0.0	228	0.025	0.27	0.0029	11.7
Bourbon County State Lake	L	2.4	8.1-8.4	127.0/0.75	295	0.016	0.14	0.0022	11.0
Bourbon County Lake	L	1.8	7.9-8.2	86.5/0.0	209	0.015	0.27	0.0039	7.3
Wilson County State Lake	L	2.5	7.8-8.4	114.25/1.0	332	0.026	0.18	0.0036	12.0
Crawford County State Lake #2	L, Sh	2.8	8.1-8.65	93.25/3.0	245	0.011	0.32	0.0028	13.0
Neosho County State Lake	Sh, L	0.9	8.1-8.5	91.0/0.5	232	0.026	0.25	0.0090	5.5
Crawford County State Lake #1	Shaly	2.3	8.3-8.8	88.75/7.25	662	0.016	0.23	0.0029	150
Strip Mine Lake at the Sunflower Pits	Shaly	2.6	8.1-8.2	94.0/0.0	3970	0.014	0.15	0.0018	1830

*Ss = sandstone and interbedded sandy shale, L = limestone and interbedded limy shale, and Sh = heavy shale and shaly clay.

TABLE IV. Some average chemical conditions in the nine study lakes. All measurements are in ppm.

Lake	Parent* Soil Material	Silica	Na	K	Ca	Mg	Mn	Cl	Br
Montgomery County State Lake	Ss	2.01	7.1	3.8	27.2	10	0.05	2.28	1.9
Woodson County State Lake	Ss, L	2.51	7.1	3.4	29.8	10	0.09	2.28	1.2
Bourbon County State Lake	L	3.47	3.4	1.5	45.2	10	0.09	1.14	1.3
Bourbon County Lake	L	1.64	4.7	2.6	32.2	10	0.05	0.0	1.3
Wilson County State Lake	L	3.44	13.2	3.3	42.7	10	0.07	19.39	1.4
Crawford County State Lake #2	L, Sh	4.34	4.9	2.1	35.7	10	0.05	0.0	1.2
Neosho County State Lake	Sh, L	1.71	6.6	3.3	30.3	10	0.05	0.0	1.25
Crawford County State Lake #1	Shaly	1.05	55.9	4.0	35.8	35	0.05	2.28	1.5
Strip Mine Lake at the Sunflower Pits	Shaly	2.54	265.0	9.5	268.0	400	0.20	8.56	1.8

*Ss = sandstone and interbedded sandy shale, L = limestone and interbedded limy shale, and Sh = heavy shale and shaly clay.

have changed little from past recordings. From the 25 lakes studied, it appears that turbidity correlates with drainage systems composed largely of soils with parent materials of heavy shale and shaly clay. All of the lakes visited developed strong thermal stratifications during the summer months with the exception of Bourbon County Lake and the strip mine lake at Crawford County State Lake #1. Even the two lakes which did not show strong thermal stratification did have oxygen depletion on their bottoms for considerable periods of time during the summer.

Surface temperatures in all of the lakes ranged near 30° C during the summer months of July and August. At Crawford County State Lake #1, the highest water temperature, 32.2° C, was recorded on July 15, 1966. All of these lakes freeze over for short periods of time during the winter.

Most of the plankton organisms studied tended to show seasonal variability in their occurrence. Two factors, temperature and light, play large roles in determining these occurrences. For instance, Asterionella and Dinobryon were not collected during the hot summer months of high light intensity from the lakes in which they occurred, while Pediastrum was most common in summer and autumn.

In only one instance was surface dissolved oxygen noted as becoming critically low in any of these lakes. This was in the strip mine lake of Crawford County State Lake #1. On the morning of August 5, 1966, it was reduced to only 4.2 ppm in the lake. Bottom dissolved oxygen was lacking.

Neosho County State Lake, the lake subject to the most rich summer algal blooms, showed the most consistant lack of oxygen on its bottom during summer thermal stratification. These factors tend to classify it as the most eutrophic of the nine lakes. For the opposite reasons, Montgomery County State Lake tends to represent the most oligotrophic lake.

All of these lakes were alkaline in nature and pH values ranged from 7.8 in Woodson and Wilson County State Lakes to 8.8 in the strip mine lake at Crawford County State Lake #1. In only three instances, once in Bourbon County Lake, and once each in Woodson and Wilson County State Lakes was surface pH recorded as being below 8.0. As a result of thermal stratification, pH decreased in the hypolimnions of all of these lakes during the summer, but acid conditions were never recorded.

Average surface bicarbonate alkalinities for the nine lakes of this study ranged between 83 and 127 ppm. Surface carbonate alkalinities averaged between zero in four lakes to 7.75 ppm in Crawford County State Lake #1. If these lakes are classified according to the Wisconsin system, it can be seen that all of them, with the exception of Woodson County State Lake which is a borderline case, are hard water lakes. Bottom bicarbonate alkalinities during summer thermal stratifications were greater than those at the surfaces of these lakes, as would be expected.

It is probably rare that the production of plant material in aquatic environments is limited by the supply of inorganic carbon, since the total carbonate of such an environment is generally in great excess (Ketchum, 1954) and is available in the bicarbonate form to most plankton organisms. The positive relationship between alkalinity and productivity in lakes and streams is well documented (Williams, 1964). Of the lakes investigated in this study, only three did not support heavy algal populations at one time or another. Of the six lakes which had abundant algal floras, all did not contain an abundance of the same species and those which did contain the same species did not contain them in similar concentrations. Only two lakes developed obvious blue-green algal blooms during the summer of 1966. Sreenivasan (1965) has noted that the optimum alkalinity for blue-green algae is considered to be between 50 and 110 ppm. According to this, seven of the lakes which I studied had optimal alkalinity characteristics for blue-green algal blooms, but only two of these exhibited blooms.

From the discussion presented here, it is apparent that alkalinity plays a part in the production of great quantities of algae, but it is also apparent that optimal conditions may exist with respect to alkalinity and still no blooms will occur. No correlation was found to exist between alkalinity and the abundance of any of the plankton organisms investigated in this study.

The average specific conductivities of these nine lakes ranged from 209 to 3970 umhos/cm^2. The strip mine lakes, in particular the one in the Sunflower Pits, had high conductivities. The 100-acre-type lakes averaged from 209 to 332 μmhos/cm^2. In general, conductance displayed a stratification similar to that of alkalinity, as bicarbonate is one of the dominant ions in the water contributing to its conductivity. Conductivity does not appear to stratify in the strip mine lake of the Sunflower Pits, perhaps because here bicarbonate does not make up such a large percentage of the total electrolyte. Among the 100-acre-type lakes, there does not appear to be any relationship between the parent soil material of their drainage systems and the specific conductance.

No correlation was found to exist between the conductivities of these lakes and the abundance of any of the plankton organisms within them.

Ketchum (1954) stated that the maximum amount of free phosphate present in many lakes is about .010 ppm. Of the nine lakes studied for this report, phosphate averaged from .011 ppm in Crawford County State Lake #2 to .026 ppm in both Wilson and Neosho County State Lakes. These nine lakes, therefore, appear to be rather high in phosphate. Due to the fact that the three lakes mentioned above produced among the largest amounts of plankton of the nine lakes, it does not seem likely that there is any relationship between the phosphate content of these lakes and their plankton production. Similarly, no relationship appears to exist between the kinds of plankton present and the phosphate concentration. For instance, in the case of the phytoplankton, of the two lakes highest in phosphate one was characterized by blue-green (Cyanophyte) algae, the other by yellow-green (Chrysophyte) algae.

Evidence has been presented that in small eutrophic lakes, all inorganic nutrient substances except phosphorous and combined nitrogen, are normally present in great excess. Experimental enrichment of water samples kept in bottles suspended in a lake demonstrate that a very great increase in crop can always be obtained solely by the addition of KNO_3 and KPO_4. A 7 to 20 fold increase is likely. It thus appears that phosphates and nitrates act as limiting factors (Hutchinson, 1944).

Phosphate is important to plankton organisms, but as conditions exist in the nine lakes of this study, other factors must be more important in determining the abundance and distribution of the plankton.

Gerloff and Skoog (1954) have carried out some interesting experiments with Microcystis aeruginosa. In these experiments, it was found that the nitrogen and phosphorous content of the cells increase with the external supply of nitrogen and phosphorous over a wide range. The amount of growth, however, remained the same over most of the range investigated. The amount of nitrogen and phosphorous taken up beyond that necessary for optimal growth was termed luxury consumption. By studying the nitrogen and phosphorous content of some of the algae of some lake blooms they were able to determine whether or not nitrogen and phosphorous contents were in the luxury range, and therefore, whether or not either of these elements was limiting growth of the algae. On further study, (Gerloff and Skoog, 1957) they found that in Southern Wisconsin lakes, nitrogen is the most important element limiting Microcystis aeroginosa, while phosphorous is not nearly as critical. I believe that such research which considers the amount of certain elements within the algae themselves in relation to luxury consumption, in addition to what may be detected in the environment, could lead to a greater understanding of algal distribution if convenient methods could be developed to isolate organisms which do not necessarily occur in blooms.

Some investigations have shown that nitrate is a readily available source of nitrogen in algal cultures (Ketchum, 1954). Ketchum (1939) found that a reduction of nitrate nitrogen to .05 ppm did not retard the growth of Nitzschia closterium. Nitrate nitrogen in the nine lakes studied for this report averaged from 0.14 to 0.32 ppm. This is well above the limiting concentration necessary for good growth of Nitzschia closterium. As was the case with phosphate, there appears to be no relationship between the nitrate nitrogen content of any of these nine lakes and the kinds or abundances of net plankton present within them. For instance, of the three lakes highest in nitrate nitrogen, one supported large blue-green algae populations, one supported large diatom populations, while the other supported no large algal populations.

Nitrite nitrogen averaged from .0018 ppm in the strip mine lake at the Sunflower Pits to .0090 in Neosho County State Lake. Within a given lake there were large fluctuations in nitrite nitrogen; for instance, in Neosho County State Lake a high value of 0.0318 ppm on October 15, 1966 and a low value of 0.0005 ppm on June 11, 1966 were recorded. This lake contained by far the greatest nitrite nitrogen concentration and was also the most conspicuous blue-green algae producer, particularly during spring and early summer when Aphanizomenon was in bloom.

Neosho County State Lake had the lowest sulfate concentration, while the strip mine lake of the Sunflower Pits had the highest concentration. Except in the strip mine lakes, where sulfate tended to be high, this ion ranged between 4.5 and 12 ppm.

Silica is a large component of the cell walls of diatoms (Round, 1965), and is therefore a macronutrient for these algae. The silica content of the nine lakes averaged between 1.05 ppm in the strip mine lake at Crawford County State Lake #1 and 4.34 ppm in Crawford County State Lake #2. From five bottom samples analyzed for silica from samples collected on August 4 and 5, 1966, it was evident that silica tended to concentrate on the bottoms of the lakes. For instance, in Crawford County State Lake #2, top silica was 3.65 ppm, while bottom silica was 7.73 ppm. From the results of silica determinations for 20 of the lakes in this study, it can not be said that silica is a dominant factor effecting the distribution of the diatoms studied in this report.

Except in the strip mine lakes, where its concentrations were quite high, sodium averaged from 3.4 ppm in Bourbon County State Lake to 13.2 ppm in Wilson County State Lake.

Potassium averaged between 1.5 and 9.5 ppm in the nine lakes studied, with the strip mine lakes having the greatest concentrations.

Calcium concentrations averaged from 27.2 ppm in Montgomery County State Lake to 45.2 ppm in Bourbon County State Lake, with the exception of the strip mine lake of the Sunflower Pits which contained about 270 ppm calcium.

Calcium tended to be more concentrated in the hypolimnions of the lakes during periods of summer thermal stratification which is the usual case brought about as a result of precipitation from the epilimnion of carbonate in the form of calcium carbonate.

Williams (1964) stated that high phytoplankton counts correspond to calcium hardness, but from the data presented on calcium in this report, it does not appear that any relationship exists between this ion alone and the plankton types and numbers present in these lakes.

Due to instrument failure, exact estimates of magnesium were not obtained, but in all of the 100-acre-type lakes, magnesium was close to 10 ppm. The strip mine lake at Crawford County State Lake #1 contained about 35 ppm, and that at the Sunflower Pits, about 400 ppm. Magnesium, therefore, was not rare in any of the lakes.

Manganese concentrations were determined for a July sampling period and ranged from 0.05 ppm in five lakes to 0.20 ppm in the strip mine lake of the Sunflower Pits. Harvey found that 0.5 to 2.0 µg/l of manganese allowed vigorous growth of Chlamydomonas, Chlorella, and members of the Cryptomonadaceae and Chrysomonadaceae (Drauss, 1958). My observed values were much greater than this, and in general it does not appear that manganese played a part in limiting the distribution of the plankton studied in this report.

Copper was not present in large enough quantities to obtain accurate estimates with the method used.

Due to a lack of iron-free water for standards, only qualitative and semiquantitative data can be given for iron. First of all it was present in all lakes. Second, by color comparisons, it could be seen that all nine lakes contained close to the same amounts of iron. The iron detected was that which passed through a 0.8 µ pore Millipore filter and did not appear responsible for the distribution or abundance of any of the plankton organisms studied for this report.

Chloride was estimated for an August sample. Wilson County State Lake had by far the highest chloride concentration, 19.39 ppm. Its plankton population, however, varied little in type from those of the other two limestone lakes. The two lakes, Crawford County State Lake #2, and Neosho County State Lake, which had the most conspicuous filamentous blue-green algal blooms were very low in chloride. However, other low chloride lakes had few filamentous blue-green algae.

Bromide concentrations averaged between 1.2 and 1.8 ppm for the nine lakes excluding Montgomery County State Lake. The strip mine lakes had the highest bromide concentrations of these eight, Montgomery County State Lake probably averaged slightly higher than these, for in an October sample, the concentration was high enough so as to be outside the accuracy of the analytical procedure used. On this date bromide was estimated to be somewhere between 1.5 and 5 ppm. It is felt that no relationship existed between bromide and plankton abundance or distribution according to the data presented here.

The Zooplankton

Table V lists the average numbers of the more common zooplankton types as investigated in this study.

Thecate amoebae were found in all of the lakes except Bourbon County Lake, and their greatest abundance occurred during the summer. The distribution of thecate amoebae does not seem limited by any of the factors investigated in this study, so their apparent absence from Bourbon County Lake can not be explained.

Ceratium was found in all of the nine lakes investigated and was present in most of the lakes on all sampling dates. This organism was by far most abundant in Neosho County State Lake, a lake which also

TABLE V. Average number per liter of some of the common zooplankters occurring in the study lakes.

Lake	Parent* Soil Material	Ceratium	Keratella	Polyarthra	Cladocera	Copepoda
Montgomery County State Lake	Ss	60	30	70	16	3
Woodson County State Lake	Ss, L	40	50	6	13	7
Bourbon County State Lake	L	60	40	2	60	7
Bourbon County Lake	L	50	40	13	16	7
Wilson County State Lake	L	70	8	8	30	9
Crawford County State Lake #2	L, Sh	70	50	5	20	8
Neosho County State Lake	Sh, L	380	40	11	90	20
Crawford County State Lake #1	Shaly	140	130	15	10	14
Strip Mine Lake at the Sunflower Pits	Shaly	3	4	2	1	3

*Ss = sandstone and interbedded sandy shale, L = limestone and interbedded limy shale, and Sh = heavy shale and shaly clay.

supported abundant copepod, cladoceran, and blue-green algal populations. Neosho County State Lake drained from soils with dominant parent materials of limestone and shale. In general, the lakes which had shale as a dominant parent soil material in their drainage systems tended to support the largest *Ceratium* populations, while those whose drainage systems drained from soils with dominant parent materials of sandstone tended to support smaller populations. With the exception of the strip mine lake at Crawford County State Lake #1, those lakes highest in *Ceratium* also tended to be high in blue-green algae. There was a positive rank difference correlation significant at the 1% level (rho = .83) between the abundance of *Ceratium* and that of copepods in these lakes.

Five rotifers, *Keratella*, *Polyarthra*, *Asplanchna*, *Tetramastix* and *Filinia* were observed in this study.

In 1921, Nordquist said that an abundance of rotifers as compared to other groups of organisms indicated a eutrophic condition, but not all people agree to this (George, 1966). Williams (1966) believed the dominant rotifers of an area were determined by the principal edaphic factors of the area, and that their abundance was determined by the amount of available food. He noted that stations with high rotifer populations were usually correspondingly rich in phytoplankton. According to Pennak, rotifers show no seasonal variation in the United States, and Wesenburg and Lund did not note marked seasonal variations in Danish waters. George, however, noted that in Delhi, rotifers showed their greatest abundance during the summer (George, 1966).

Keratella was present in all of the nine lakes including the strip mine lake of the Sunflower Pits, and was found in most of the lakes on all of the sampling dates. Its greatest abundance was in the strip mine lake at Crawford County State Lake #1, but its general abundance did not appear to correlate with the parent soil materials of the lake drainage systems. *Keratella* did not show any seasonal variation in the nine lakes studied here, and it did not appear that the trophic status of the lakes had any relationship to its abundance.

Polyarthra was found in all of the lakes studied. It was least abundant in the strip mine lake at the Sunflower Pits, and was by far most abundant in Montgomery County State Lake. In general, mid-summer through fall appeared to be the periods of greatest *Polyarthra* abundance. The distribution of this organism seemed to favor those lakes not containing great amounts of soil with dominant parent materials of limestone in their drainage systems. There was a negative rank-difference correlation significant at the 5% level (rho = -.80) between *Polyarthra* abundance and the concentration of calcium in these waters, and negative rank-difference correlations significant at the 1% level between the abundance of this organism and the abundance of *Dinobryon* and *Fragilaria* (rho = -.83 and -.88 respectively).

The rotifer *Asplanchna* was not very abundant in any of the nine lakes. It was most abundant in Wilson County State Lake where it averaged 3 organisms per liter, and was absent from both of the strip mine lakes. It was most common during the summer months. There was a rank-difference correlation significant at the 1% level (rho = .85) between the average abundance of *Asplanchna* and that of cladocera, and a rank difference correlation significant at the 5% level (rho = .81) between the average abundance of Asplanchna and that of Coelosphoerium.

Filinia was observed in Woodson County State Lake on July 14, 1966. Its concentration was estimated at 32 organisms per liter. According to Rutner (1963), this organism prefers deep waters, so it is possible that the sampling method used to collect these organisms may have given misleading values of what may actually have been present in this lake and the others.

Tetramastix was observed in Neosho County State Lake on Feb. 12, 1967 at an estimated concentration of 68 organisms per liter.

Cladocera showed their greatest abundance in Neosho County State Lake. On October 15, 1966, a date when Bourbon County State Lake was sampled from the shore, 520 Bosmina per liter were collected. Whether or not this condition existed throughout the lake is not certain. No cladocerans were found in the strip mine lake of the Sunflower Pits. In general, the cladocerans were most abundant in those lakes with much limestone as the parent soil materials of their drainage systems.

In 1921, Nordquist established that the distinction between oligotrophic and eutrophic ponds could be made with reference to the zooplankton of the ponds. He showed that oligotrophic ponds were characterized by a dominance of Cladocera with few or no rotifers, and only few copepods during the summer; eutrophic ponds on the other hand, he said, were characterized by large numbers of rotifers and abundant cyclops, while Cladocera were less frequent (Fritsch, 1931). The most eutrophic lake of the nine I studied, Neosho County State Lake, had a greater abundance of Cladocera than copepods, but still had more copepods than any of the other lakes. It appears, therefore, that Nordquist's statement does not hold for these lakes.

Neosho County State Lake contained the greatest concentration of copepods. There did not appear to be any seasonal variation in their occurrence, and their occurrence did not appear to correspond to lakes with drainages from soils of any particular type of parent soil material.

The Phytoplankton

Table VI lists some of the more common chlorophyte and chrysophyte algae investigated in this study and gives their average abundance as they occurred in the nine lakes. Table VIII does the same for the blue-green algae.

Pediastrum was found in all of the nine lakes investigated. Except where the high dissolved solid content of the strip mine lakes may have resulted in the low numbers of *Pediastrum*, no correlations appear to exist between *Pediastrum* concentrations and lake chemistry or area geology.

Staurastrum was found in all of the lakes studied, but was least abundant in the strip mine lake of the Sunflower Pits. Among these nine lakes, *Staurastrum* was most abundant in those lakes which had clear waters and drainage systems with much soil of limestone parent material. They were most common during the spring and fall of the year. There was a positive rank-difference correlation significant at the 5% level (rho = .76) between the average abundance of *Staurastrum* and that of *Fragilaria*. There was a negative rank-difference

TABLE VI. Average number per liter of some chlorophyte and chrysophyte cells and/or colonies occurring in the study lakes.

Lake	Parent* Soil Material	Pedi-astrum	Staura-strum	Volvox	Fragi-laria	Asterio-nella	Dino-bryon
Montgomery County State Lake	Ss	100	4	0	0	0	0
Woodson County State Lake	Ss, L	6	30	0	220	760	130
Bourbon County State Lake	L	30	90	0	3980	2	21,500
Bourbon County Lake	L	55	100	3	1780	180	630
Wilson County State Lake	L	950	50	1	2720	370	4,040
Crawford County State Lake #2	L, Sh	2,410	120	2	660	4,140	60
Neosho County State Lake	Sh, L	14	9	0	1	0	0
Crawford County State Lake #1	Shaly	5	11	0	7	10	7
Strip Mine Lake at the Sunflower Pits	Shaly	3	2	0	1	0	0

*Ss = sandstone and interbedded sandy shale, L = limestone and interbedded limy shale, and Sh = heavy shale and shaly clay.

correlation significant at the 5% level (rho = -.71) between Staurastrum and Polyarthra.

Volvox was found in three of the lakes investigated: Bourbon County Lake, Wilson County Lake, and Crawford County State Lake #2. It appeared to prefer cooler temperatures, as it was not observed during July or August. Table VII shows some of the pertinent factors which may be involved in the distribution of Volvox. From this table, it can be seen that Volvox was restricted to clear water lakes with drainage systems containing soils with dominant parent materials of limestone, or limestone and shale, and which had relatively high weight ratios of Na + K / Ca.

Several pulses of a small filamentous green algae were observed in four of the nine lakes studied. Their principal occurrence was in those lakes which drained soils of limestone, and limestone and shale parent materials. Wilson County State Lake was the only exception. It did not contain any of these filamentous green algae. Perhaps its relatively high sodium content played a part here, for a rather strong negative correlation existed between sodium and these algae.

Fragilaria was found in all lakes except Montgomery County State Lake and was only observed once (two colonies) in Neosho County State Lake. Montgomery County State Lake was a semi-clear water lake which drained soils of dominantly sandstone parent materials and supported no blooms, while Neosho County State Lake was a relatively turbid lake which drained soils of dominantly limestone and heavy shale parent materials and supported relatively heavy blue-green algal blooms. The strip mine lakes were low in Fragilaria. Fragilaria appeared in

TABLE VII. Weight ratios of Na + K / Ca, dominant parent soil materials, and average secchi disc readings for the seven 100 acre lakes.

Lake	K + Na / Ca	Parent Soil* Materials of Drainage	Secchi Disc (meters)
Montgomery County State Lake	.41	Ss	1.1
Woodson County State Lake	.36	L, Ss	2.1
Bourbon County State Lake	.12	L	2.4
**Bourbon County Lake	.24	L	1.8
**Wilson County State Lake	.39	L	2.5
**Crawford County State Lake #2	.21	L, Sh	2.8
Neosho County State Lake	.35	L, Sh	0.9

*L = limestone and interbedded limy shale, Ss = sandstone and interbedded sandy shale, and Sh = heavy shale and shaly clay.

**Volvox present.

abundance only in those lakes which drained chiefly from soils of limestone parent materials. There was a rank-difference correlation significant at the 1% level (rho = .93) between the abundance of Fragilaria and Dinobryon, and rank-difference correlations significant at the 5% level between Fragilaria and Staurastrum abundance, secchi disc readings (water transparency), and calcium concentration (rho = .76, .80, and .81 respectively).

In 1904, Wesenberg and Lund observed that 16° C seemed to be the upper limit controlling blooms of Fragilaria crotonensis, and blooms were common in the spring and fall. Hutchinson found a different situation in Linsley pond, where summer blooms were also common at temperatures between 24.9 and 29.0° C (Hutchinson, 1944). George (1966) reported that in the tanks of Delhi Fragilaria maxima occurred most commonly in the winter, at which time the water temperatures ranged from about 15 to 23° C. In North Carolina, Whitford (1960) reported that Fragilaria was very rare at lower elevations except in late winter, but was common in streams at high elevations throughout the year where temperatures remain low during the summer. In the lakes in which I found Fragilaria, it was present at all times of the year, but the heaviest blooms were observed in the spring and fall when water temperatures ranged between 16 and 23° C.

The occurrence of Asterionella corresponded closely with that of Fragilaria and Dinobryon. It occurred most commonly in those lakes which drained large amounts of soil with limestone parent materials and with clear water. Rank-difference correlations significant at the 5% level existed between Asterionella abundance with both secchi disc readings (water transparency) and sulfate concentration (rho = .74 and .71 respectively). Asterionella was absent from all of the lakes during July and August when temperatures ranged from 26 to 31° C, but was common during all other sampling periods.

Hutchinson (1944) stated that in Linsley Pond there was no evidence that the appearance of Asterionella formosa depended on inorganic nutrient levels. Lund, working on Windermere in England however, has shown that the silica content of this mere ranged near 2 ppm in March, and observed that as Asterionella formosa increased in numbers to 10^3 or 10^4 cells per ml., the silica concentration began to drop. When it dropped to 0.5 ppm, the growth of A. formosa ceased, and the bloom was over. Consequently, 0.5 ppm was considered a limiting factor for large accumulations of Asterionella formosa (Fogg, 1965). It can be seen from Table IV that all of the lakes investigated in this study contained silica in excess of this amount, but still not all of them developed Asterionella blooms or even had any Asterionella at all.

Experiments have shown that Asterionella rapidly changes its growth rate when temperature or light intensity are changed. High temperature and illumination enhance a faster growth rate (Round, 1965). Rutner (1963) noted that Asterionella prefers deep water. As Neosho County State Lake is relatively turbid, illumination would be only slight in its deeper waters. These factors could play a part in determining the absence of this organism from this lake. Whitford (1960) stated that Asterionella has a low temperature, high light requirement. From their appearance in Southeastern Kansas clear water lakes except during July and August, it would appear that this is the case in this area. Williams (1964), however, thought that Asterionella formosa appeared to be regulated more by the length of the photoperiod than by temperature, when he pointed out that Asterionella blooms from the Great Lakes to Florida and Texas all at the same time.

The occurrence of Dinobryon in these lakes was much the same as that of Fragilaria, and there was a positive rank-difference correlation significant at the 1% level (rho = .93) between them. Dinobryon was most abundant in clear water lakes with drainage systems from soils dominantly of limestone parent material. Of the samples collected for this study, Dinobryon proved to be most abundant in late May, June, and in February. Water temperatures during these times ranged between 3.5 and 27° C. Except in Bourbon County State Lake, Dinobryon was absent during July and August when water temperatures ranged from 27 to 31° C, and it was only present in low numbers in Bourbon County State Lake. Positive rank-difference correlations significant at the 5% level were found between Dinobryon and both secchi disc readings (water transparency) and calcium (rho = .77 and .73 respectively). A negative rank-difference correlation significant at the 1% level (rho = -.83) was found between Dinobryon and Polyarthra concentrations.

Whitford (1960) stated that Dinobryon has a low temperature, high light, requirement. The correlation that existed between the Dinobryon in the lakes of this report and water transparency tends to strengthen Whitfords statement where it concerns light intensity, but that the Dinobryon of these lakes bloomed with water temperatures as high as

27° C does not strengthen that part of his statement concerning low temperature.

Hutchinson noted that the Dinobryon populations of Linsley Pond were surpressed as long as a maximal spring population of other forms could be maintained. Dinobryon populations appeared to increase only after the major components of the spring maximum. Due to the fact that my sampling was not begun until May, 1966, when Dinobryon blooms were already apparent, this view cannot be directly upheld or refuted. However, from comparisons of early May, 1967 with late May, 1966 when Dinobryon was in bloom, Hutchinson's statement does not seem unreasonable. Ketchum (1954) said that preliminary observations indicated that additions of .005 ppm or more of phosphorus (or .015 ppm PO_4) to Lake Erkin water was sufficient to inhibit growth of Dinobryon. He said that it was of interest that Dinobryon blooms occurred after a decline of other species. The inhibition of growth by relatively low concentrations of phosphorus may be the explanation for the failure of Dinobryon to bloom except following growth and resultant assimilation of nutrients by other species. My data only partially uphold this thought. For instance, large Dinobryon blooms existed in Bourbon County State Lake on May 28 and June 23, 1966 when phosphate was .017 and .019 ppm, respectively. On June 10, 1966, however, the Dinobryon population was much smaller, and phosphate was zero ppm, but on Feb. 12, Wilson County State Lake exhibited a large pulse of Dinobryon although phosphate was zero. In these cases phosphate did not appear to influence the occurrence of Dinobryon.

In the cases of the three organisms, Asterionella, Fragilaria and Dinobryon, Crawford County State Lake #1 was an outstanding exception to their distributional pattern, for this lake is thought to lie mainly in a basin of shaly material but still contained all three of these organisms. It is a strip mine lake, and therefore may not be comparable to the other lakes.

Table VIII lists some of the common blue-green algae investigated in this study and gives their average abundance as they occurred in the nine lakes.

Prescott (1960) noted that blue-green algae developed well only in waters well supplied with phosphate and nitrate. He said that this was due in part to the highly proteinaceous nature of their protoplasm. Hasler (1963), however, pointed out that blue-green algae which had been studied did not have unusually high phosphate requirements. In fact, relative to other organisms, their requirement seemed low. In addition, Hutchinson (1944) believed that the Anabaena of Linsley Pond were probably independent of nitrate and ammonia. He noted Pearsal's generalization that blue-green algae tend to appear on a lake at that time of year when it is in its lowest trophic state. He went on to say that we are thus faced with a paradox, that while summer blooms of blue-green algae are characteristic of eutrophic waters, the seasonal conditions for the appearance of such blooms are satisfied at times when the more obvious inorganic nutrients are reduced to extremely low concentrations.

TABLE VIII. The average number of blue-green trichomes or colonies per liter in the nine study lakes.

Lake	Parent* Soil Material	Anabaena spiroides	Other Anabaena	Coelosphaerium	Aphanizomenon
Montgomery County State Lake	Ss	0	0	9	0
Woodson County State Lake	L, Ss	0	60	170	0
Bourbon County State Lake	L	0	270	320	0
Bourbon County Lake	L	350	30	0	0
Wilson County State Lake	L	7	1300	3130	0
Crawford County State Lake #2	L, Sh	230	8920	2610	0
Neosho County State Lake	Sh, L	1	2640	5640	88,800
Crawford County State Lake #1	Shaly	0	0	0	0
Strip Mine Lake at the Sunflower Pits	Shaly	0	0	0	0

*Ss = sandstone and interbedded sandy shale, L = limestone and interbedded limy shale, and Sh = heavy shale and shaly clay.

Anabaena spiroides was found in the same lakes as was *Volvox*. In addition, however, two trichomes were found in each of a July and an August sample at Neosho County State Lake.

Anabaena, excluding *Anabaena spiroides*, were most abundant in those lakes whose drainage systems contained soils with much limestone and shale as their parent materials. They were most abundant during the summer months of July and August.

Coelosphaerium was found in greatest numbers in those lakes in which limestone was one of the dominant parent soil materials of the drainage system. Where it was abundant, it was present throughout the year.

Neosho County State Lake, a lake which drains soils of limestone and shale parent materials, supported *Aphanizomenon* blooms during both years of this study. In 1966, they were present in great numbers until June 11, (518,560 trichomes per liter), but were absent on June 24. In 1967, they were again present on May 4 at a concentration of 257,400 trichomes per liter. The water temperatures on these dates ranged from 17.5 to 28° C. Other than its turbidity, brownish color, relatively high nitrite, and relatively low sulfate, the physical-chemical conditions in Neosho County State Lake which were measured were not strikingly different from those of the other lakes.

Oscillatoria was present in five lakes. It was absent from Montgomery County State Lake, Bourbon County State Lake, and the strip mine lakes. Although limestone appears to be a favorable factor in its distribution, as was the case with *Anabaena spiroides*, it was never observed in Bourbon County State Lake. Perhaps the low Na + K / Ca ratio was responsible.

The dominant characteristics of the nine lakes as presented throughout this paper are summarized in Table IX. It should be noticed particularly that Fragilaria and Dinobryon are those plankton algae most strongly characterizing the lakes draining from soils of dominantly limestone parent material. It should also be noted in passing down the list of lakes, that as the dominant parent soil materials of the drainage systems pass from sandstone, through limestone, and then toward shale, the trophic classification of the lakes shifts from more oligotrophic to more eutrophic in nature.

TABLE IX. Some of the more outstanding characteristics of the nine lakes.

Lake	Dominant* Parent Soil Material	Trans- parency	Apparent Water Color	Characterizing Physical-Chemical Conditions	Characteristic Plankton	Trophic Classification
Montgomery County State Lake	Ss	semi- clear	blue-green	high Br	Polyarthra Pediastrum	oligotrophic
Woodson County State Lake	L, Ss	clear	blue-green	-----	Oscillatoria	mesotrophic to oligotrophic
Bourbon County State Lake	L	clear	blue-green	high Ca, HCO_3 low K, Na	Fragilaria Dinobryon Coelosphaerium	mesotrophic
Bourbon County Lake	L	clear	blue-green	low sp. cond.	Fragilaria Dinobryon Anabaena spiroides	mesotrophic
Wilson County State Lake	L	clear	blue-green	high sp. cond., high Na, Cl	Fragilaria Dinobryon Coelosphaerium	mesotrophic
Crawford County State Lake #2	L, Sh	clear	blue-green	high pH	Anabaena spp., A. spiroides, Asterionella, Pediastrum; general abundance of many other forms	mesotrophic
Neosho County State Lake	Sh, L	turbid	brownish	high NO_2 low SO_4	Aphanizomenon Coelosphaerium Anabaena spp.	eutrophic

TABLE IX. (Continued)

Lake	Dominant* Parent Soil Material	Trans-parency	Apparent Water Color	Characterizing Physical-Chemical Conditions	Characteristic Plankton	Trophic Classification
Crawford County State Lake #1	Shaly	clear	blue-green to emerald green	high pH, higher than average in dissolved solids particularly Na, SO_4	Keratella, Ceratium Copepoda, with chlorophyte and chrysophyte algae	-----
Strip Mine Lake at the Sunflower Pits ,	Shaly	clear	blue-green to emerald green	high in dissolved solids, esp. Na, Ca, Mg, SO_4	sparce plankton, but Ceratium, Staurastrum, Keratella, Pediastrum, Polyarthra and copepods not uncommon.	-----

*Ss = sandstone and interbedded sandy shale, L = limestone and intervedded limy shale, and Sh = heavy shale and shaly clay.

SUMMARY AND CONCLUSIONS

Of the seven 100-acre-type lakes investigated for a one year period, six were hard water lakes and one, Woodson County State Lake, was borderline between this and the next lowest type on the hardness scale. According to the trophic classification, they appeared to be mostly mesotrophic in nature with the extremes lying possibly in oligotrophy and eutrophy. Due to its low numbers of plankton, lack of blue-green algae, predominance of green algae and persistance of bottom dissolved oxygen, Montgomery County State Lake was considered to be the most oligotrophic lake studied. Neosho County State Lake was the most eutrophic of the seven 100-acre-type lakes as indicated by its extensive blooms of blue-green algae, particularly Aphanizomenon, and its almost persistant lack of bottom dissolved oxygen. In general, as the dominant parent soil materials of the drainages of these lakes vary from sandstone to limestone and then to shale, the nature of the lakes varies from more oligotrophic to more eutrophic in nature.

A seasonal variation of the plankton occurred in all of the nine lakes investigated. Ceratium, Staurastrum, Fragilaria and Anabaena spiroides appeared in low numbers during the winter. Pediastrum and Asplanchna appeared in highest numbers in summer and fall, while Dinobryon and Asterionella were lowest in number during mid-summer and fall. Thecate amoebae and Anabaena spp. were highest in number during the summer while Volvox was lowest at this time. Aphanizomenon occurred during the spring of the year, while Coelosphaerium, Keratella, and Polyarthra did not show any sharp seasonal variations.

The strip mine lakes were located in areas where the natural geology has been greatly disturbed by coal strip mining and may, therefore, not be comparable to the other lakes. Of the two strip mine lakes studied, Crawford County State Lake #1 appeared to contain the least drastic dissolved solid concentrations and displayed a light, but seemingly normal, mesotrophic to oligotrophic plankton. The strip mine lake at the Sunflower Pits, however, contained a much higher dissolved solid concentration and supported a very sparce plankton population.

The soils of the area under study were derived from parent materials of limestone, sandstone, or shale. No obvious chemical differences appeared to exist in these lakes which showed very strong correlation to parent soil material. Alkalinity, calcium, and conductivity tended to be lower in the two lakes draining soils of primarily sandstone parent material, but due to the small sample and variation from lake to lake, it could not be said with confidence that any significant chemical differences existed between the lakes draining from these various soil types. Turbidity, however, judging from the 23 lakes visited on May 3 and 4 seemed to correlate strongly with drainage from soils of heavy shale and shaly clay parent materials.

Differences in the plankton of lakes from areas of different parent soil material appeared much more obvious than differences in the water chemistry. *Staurastrum* was not wholy limited to, but appeared to do better in lakes which drained soils of limestone parent materials. *Fragilaria*, *Asterionella*, and *Dinobryon* seemed to be even more strongly influenced by this factor. Turbidity, as judged by the condition of Neosho County State Lake, may also have been a factor involved in the distribution of these organisms. Anabaena spiroides and Volvox showed a similar trend in distribution as the above organisms, but did not appear in Bourbon County State Lake, a lake which also drains from soils of limestone parent material. In this case, the low Na + K / Ca weight ratio (.12) may be a possible factor preventing their existance in these lakes. The small, planktonic, green filamentous algae were also found most commonly in limestone areas, but in this case Wilson County State Lake never supported any of these. Perhaps the relatively high sodium content of this lake played a part in the exclusion of these algae.

Anabaena was found most commonly in those lakes which drained soils of both limestone and shale parent materials. For instance, Crawford County State Lake #2 and Neosho County State Lake supported the largest Anabaena spp. populations. Aphanizomenon bloomed only on Neosho County State Lake. Coelosphaerium was not found in Montgomery County State Lake, a lake draining soils of sandstone parent material, nor in Bourbon County Lake, one draining soils of limestone parent material.

In Southeastern Kansas, therefore, it seems apparent that some kind of pattern does exist in the distribution of many plankton organisms. The distribution seems to be most obviously related to the parent soil material of the lake drainage systems, but not so obviously related to the water chemistry of these lakes.

Larger samples would perhaps reveal more striking correlations where water chemistry is concerned. As it seems apparent that the distribution of some plankton correlates quite strongly with the parent soil material of the lake drainage systems, it would be extremely rewarding to be able to show some definite relationships between the parent soil materials of a lake's drainage system and the water chemistry of the lake. Much more work is apparently needed in this aspect of the study.

The question arises as to whether the relationships pointed out in this report hold true for other regions. Much work needs to be done from this point of view, and conducting such an extensive investigation is entirely out of the question for any one person except on a long term basis. As yet, our understanding of plankton distribution seems pretty haphazard, but as yet, few works are complete enough to really make any definite statements. The large scope of the problem and lack of coordination between workers involved seem to be the biggest obstacle.

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