LAKE MICHIGAN STUDIES

Special Report Number LM 4

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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BIOLOGICAL INVESTIGATIONS

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ENVIRONMENTAL PROTECTION AGENCY

LAKE MICHIGAN STUDIES

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BIOLOGICAL INVESTIGATIONS

April 1963

U. S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Great Lakes-Illinois River Basins Project

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INTRODUCTION

This report presents information obtained from biological studies in Lake Michigan between April 24, 1962 and December 4, 1962. Sampling stations were established at intervals of approximately ten miles throughout the lake; on 1, 4, 7 and 10 mile contours from the shoreline in the southern basin; and at intervals of two or three hundred yards in Milwaukee and Chicago harbors. The sampling stations on the one to ten mile contours are referred to as inshore stations in this report.

These biological studies were made for the purpose of: (1) evaluating the general biological condition of the lake, (2) defining areas adversely affected by wastes from tributary streams and sewer outfalls, and (3) supplementing and substantiating chemical, bacterial and physical data.

PARAMETERS: DEFINITIONS AND SIGNIFICANCE

Phytoplankton

The suspended microscopic plant life, called phytoplankton (or planktonic algae), are only slightly motile and exist at or near neutral buoyancy. As such they are subject to lake currents and represent the microflora of the sampling site only at the time of sampling. Favorable conditions of light, temperature, and water movement produce amounts of phytoplankton that increase with the availability of nutrients. Many inorganic elements are required for algal cell growth, including nitrogen, phosphorus, potassium, calcium, and iron (21). Organic substances are also required. Provasoli (26) has shown that vitamin B12, thiamine and certain other organic compounds are necessary for algal growth. Bogan (1) demonstrated that algae reproduce rapidly when phosphate phosphorus is added to water, and continue to reproduce as more phosphorus is added. However, nitrogen and other nutrients must also be present if algal production is to continue. Sawyer (2) concluded that an inorganic nitrogen concentration of 0.30 mg/l and a soluble phosphorus concentration of 0.01 mg/l could produce nuisance algal blooms. Since plankton store phosphorus in excess of their needs,nitrogen may be a more critical limiting factor for algal production than phosphorus (22). Mackenthun (24) suggests that "the initial stimulus for algal production is supplied by dissolved phosphorus and that a continued high rate of nitrogen supply does not appear to be necessary for continued algal production. Recycling of nutrients within the lake basin is sufficient to promote algal blooms for at least a number of years."

The kinds of algae constituting a standing crop are important. Several species of the blue-greens and several other algal forms impart objectionable tastes and odors making water treatment difficult and expensive (25). Certain species of the Chlorophyceae (green algae), the Chrysophyceae (brown algae) and Bacillarieae (diatoms) are common in oligotrophic lakes(27, 3). The diatoms *Tabellaria*, *Asterionella*, *Synedra*, and *Fragilaria* are usually the predominant algae in Lakes Michigan and Superior (3), both oligotrophic. On the other hand, some of the euglenoids, blue-greens, and diatoms appear to favor nutrient-enriched waters of eutrophic lakes. Species of *Anacystis*, *Oscillatoria*,*Stephanodiscus*, *Cyclotella* and *Melosira* often predominate eutrophic lakes (14). They are also the predominant forms in many nutrient enriched midwestern streams (3).

Relationship of Algae to Eutrophication

Historically, nutrient enrichment of lakes has increased biological productivity. This is known as eutrophication, or lake aging (4). Eutrophication is primarily manifested in increasing densities of planktonic algae. When nutrients for the growth of aquatic plants become available the planktonic algae develop. As the concentration of nutrients becomes greater the density of algal growth also may become greater. Algae are important elements of the food chain and beneficial in moderate amounts. They only become troublesome when they become too numerous, and particularly troublesome if the blue-greens become predominant. An overabundance of planktonic algae results in a green murky water which sometimes produces unpleasant odors and unsightly scums. As the algae become more numerous, the transparency of the water decreases and sunlight is denied the rooted aquatic plants on the lake bottom. Water filtration plants experience difficulty through tastes and odors and clogging of sand filters, and industrial water users must combat slime and corrosion (25) (5).

The nutrients that support planktonic algae also promote the development of attached algae which cover all suitable substrata wherever sufficient light can penetrate. Lake Erie has exhibited luxuriant growths of an attached algal form called Cladophora for many years (29) and more recently these algae have become a nuisance in certain areas of Lake Ontario (6) and Lake Michigan (8). They break loose as they mature, or during storms, and litter the beaches, foul fishing nets, and clog water intake screens.

In the deeper areas of the eutrophic lake, more particularly below the thermocline, dissolved oxygen values may be drastically reduced due to the oxygen demand exerted by the decay of biological materials (28) (12). The algae which become dense during the summer months die off and are succeeded the next year by another crop of algae. As the algae die, they settle to the lake bottom and are attacked by microorganisms that, along with the macro-animal forms in the bottom ooze, exert an oxygen demand. As the years progress nutrient levels rise and algal densities increase; the demand and subsequent diminution of oxygen below the thermocline increases accordingly.

Eutrophication may be either natural or induced. A lake undergoes natural eutrophication as the nutrients that support algal growth enter the lake from the watershed. Algae in their growth functions use the mineral nutrients that have been leached from the soil. If the soil is fertile, nutrients for algae are likely to be abundant. During the warmer months algae populations tend to increase up to the point where one of the essential nutrients has been depleted. Since nitrogen and phosphorus are not abundant in young glacial lakes, those nutrients are utilized as they become available. As nutrients are continually fed by leaching from the soils in the drainage area and the concentration of those nutrients rises, more planktonic algae develop. The eutrophic lake exhibits periodic algal blooms that may cause the nuisance conditions discussed previously.

The eutrophication of a lake is accelerated by the addition of nutrients other than those from natural sources (4). Treated sewage contains high concentrations of the nutrients required for algal growth and has been responsible for induced eutrophication of many lakes throughout the world. Unfortunately, the conventional sewage treatment facility removes only part of the growth nutrients in sewage. The Zurichsee, a deep, 16,500 acre, glacial lake in the Swiss Alps, is a classic, much-studied example of induced eutrophication through the introduction of domestic wastes (4). The lake is composed of two basins separated by a narrow passage. The upper basin received no sewage and remained essentially unchanged during the five decades that the lower basin received sewage from communities with a combined population of about 100,000. The basin receiving sewage changed from a clear-water lake to one murky with algae, and finally to advanced aging where the noxious blue-green algae predominated. The populations of deepwater trout and whitefish diminished early in the process and coarse fish became dominant.

The Madison, Wisconsin lakes have had a similar history, as have numerous less-publicized ponds and small lakes throughout our country (2). Lake Erie has undergone considerable change in the past 25 years and recent investigations indicate that it is becoming an eutrophic lake (7).

Lake Michigan is considered an oligotrophic lake, or one that is deep, clear, and contains little organic material.

However, long-term records of plankton populations in Lake Michigan at Chicago indicate a gradual rise over the past fifty years (9).

Benthic Fauna

The kinds and numbers of benthic fauna inhabiting a particular lake area are determined by the characteristics of the substratum, the quality of the water, and certain physical features such as morphometry of the basin, currents, wave action, temperature, light and depth (12).

The habitats suitable for the predominant Lake Michigan organisms are as follows (10):

Organic sediment, turbid water:

Oligochaeta (sludgeworms)
Tendipedidae (midge larvae)
Hirudinae (leeches)
Pulmonata (air-breathing snails)

Sand and gravel, clear water:

Amphipoda (scuds)
Prosobranchia (gill-breathing snails)
Sphaeriidae (fingernail clams)

There are three major zones of biological productivity on a lake floor. The littoral zone extends from the water's edge to the lakeward limit of rooted aquatic vegetation. The sublittoral zone extends from the littoral zone lakeward to the upper limit of the hypolimnion. The profundal zone includes all of the lake bottom up to the upper limits of the hypolimnion.

The littoral and sublittoral zones are usually populated by insects and molluscs which often comprise as much as 70% of the total number of organisms. The benthic population of the profundal zone is usually composed of a great variety of species but only a few representatives of each (12).

Deleterious compounds such as toxic metals could render the area unsuitable for many organisms. The nature of the bottom would also alter the speciation of the benthic populations. For example, organic sediments provide a suitable habitat for oligochaetes and tendipedids but not for some of the amphipods and molluscs.

One genus of the Amphipoda, Pontoporeia, was found in biological collections from all areas of Lake Michigan, and was the predominant bottom dwelling organism in areas not greatly influenced by organic sediments. The relative scarcities of Amphipoda and concomitant abundance of Oligochaetes are, therefore, considered reasonable indicators of lake areas subjected to organic enrichment if other conditions are favorable to its growth.

Organic Matter

The organic matter in lake water is either dissolved or particulate. This determination deals with the particulate organic matter which consists of phytoplankton (minute plants), zooplankton (minute animals), and non-living organic matter. The bacteria and smallest algae, and the fishes are not included.

The amount of organic matter per cubic meter of water is a gross measure of the biological productivity potential. When considered with phytoplankton densities and light penetration, the measure of organic matter may be useful in the evaluation of abnormal values for phytoplankton and certain chemical and bacteriological data. In 1959 a series of vertical plankton tows in the middle of Lake Ontario yielded values ranging from 8 mg/m^3 to 80 mg/m^3 (13).

High concentrations of organic matter in harbor areas would not necessarily indicate high biological productivity. A study of phytoplankton densities might reveal low values, in which case the organic materials would be suspected as being from sewage or industrial wastes. Therefore, in interpretation of the data, any known sources of organic wastes which influence the lake area must be considered. Chemical data from samples taken concurrently should supplement the biological information.

Light Penetration

Water transparency from the lake surface to a given depth is directly related to transmission of light energy and the consequent production of biological materials (12). If all other growth factors are present, optimum light remains as the limiting growth factor. While the method for determining transparency has inherent faults due to surface ripple, surface reflection, angle of the sun, wave action, color, and variations among humans in ability to see, the fact remains that the light that penetrates to a submerged object is a light source for photosynthetic plants.

Measurement of transparency has long been used by limnologists and the value of these data is therefore enhanced by correlations of transparencies and other pertinent data, such as phytoplankton densities, in one situation with the same data revealed in another situation. For example, Rawson (14) in his studies of six oligotrophic lakes and six eutrophic lakes in Canada found that transparencies less than ten feet occurred under algal bloom conditions in the eutrophic lakes. He also indicated that transparencies of 20 feet or more were common in the oligotrophic lakes. Investigators at Lake Washington, Seattle also reported that transparencies of the lake water decreased as phytoplankton densities increased (15).

Colloidal and suspended matter emanating from the shores produce high turbidities and reduce the transparency of the water. This in turn results in a reduced phytoplankton density. Therefore, light penetration measurements are more meaningful when phytoplankton populations are determined for the same waters at the same time.

METHODS AND PROCEDURES

All samples of biological materials were collected by biologists working cooperatively with other Project scientific personnel. Samples were taken at the same times and places as the samples taken for chemical, bacterial, and physical analyses. The methods and equipment were those described in either "Standard Methods for the Examination of Water and Wastewater," 11th Edition (16), or "Limnological Methods," Welch, 1948 (17). Field equipment is described in Special Report LM-2"Sampling Surveys." That report also indicates sampling station locations and sampling depths.

Laboratory methods followed those described in the above publications.

1. Phytoplankton samples were preserved in the field by adding enough formalin to effect a 3% solution in the water sample. One milliliter of the sample in a Sedgwick-Rafter counting cell was examined microscopically in such a way that one-twentieth or one-tenth of the cell was observed. The microscope was fitted with 10X oculars and a 20X objective for counting, and 43X and 97X objectives for identification of the organisms. Each one-celled alga, filament, and colony was counted as one organism. Results were tabulated as number of individual organisms per milliliter of sample.

2. Bottom-dwelling animals which had been dredged from the lake bottom were sifted with a No. 30 U.S. Standard sieve to remove fine particles. The organisms were then picked from the sieve and preserved with formalin. In the laboratory they were washed with water, preserved with alcohol, sorted by families, identified and counted. Results at each sampling station were recorded as numbers of organisms per square meter of lake bottom.

3. Organic matter at each sampling station was determined by lowering a 0.5 meter No. 20 plankton net until the weight suspended below touched the lake bottom, then raising it to the surface. All of the material large enough to be retained was washed into containers, preserved with formalin, and returned to the laboratory. In the laboratory the dry weight at 105°C and the ashed weight at 600°C were determined. The loss due to ignition represented the organic matter (except the smallest plankters called nannoplankton) in a column of water 0.5 meter in diameter from 1.5 meters off the bottom to the surface. The data are reported as milligrams of organic matter per cubic meter (mg/m^3) of water.

4. Light penetration of the water at each sampling station was determined by an eight inch diameter disc (Secchi disc) having alternating white and black quadrants. The disc was lowered in the water by a graduated line until it disappeared, raised until it reappeared, and the average of those two depths recorded. Measurements are reported in meters and tenths of meters. When a rough sea made visibility or reasonably accurate marking of the line difficult, no measurements were recorded.

RESULTS

To facilitate analysis the data are tabulated by lake sections as follows:

Southeast Quadrant	South and east of Lat. 43°30' Long. 87°00'
Southwest Quadrant	South and west of Lat. 43°30' Long. 87°00'
Northern Basin (except Green Bay)	North of Lat. 43°30'
Green Bay	
Milwaukee Harbor	
Chicago Harbor	

The data are summarized by showing the frequency at which ranges of values occurred at Sampling Stations 1, 4, 7, 10, and beyond 10 miles from shore. No allowance has been made for seasonal differences in the tables, but the phytoplankton densities are presented graphically by lake cruises in chronological order. Two cruises in October and November were concurrent. The data obtained during those months are shown in Figure 7.

Intensive sampling was carried out in the southern basin and at widely separated stations in the northern basin. Therefore,the results presented and the conclusions that follow will necessarily specify conditions that exist in the southern basin and generalize on the biota of the northern basin. Each of the parameters will be discussed separately.

Phytoplankton

Since inorganic nitrogen and dissolved phosphorus are considered essential for algal growth, the concentrations of these nutrients in Lake Michigan were compared with phytoplankton data.

The averages for nitrate nitrogen and total phosphate, as determined by the Great Lakes-Illinois River Basins Project (and reported in Special Report LM-3, "Chemical and Physical Investigations") were 0.12 mg/l and 0.01 mg/l, respectively; inshore concentrations as high as 0.36 mg/l and 0.27 mg/l, respectively, were found.

The densities of phytoplankton generally followed the same pattern as nutrient concentrations, except in surface samples where total phosphate levels were high (0.04 mg/l) only during the summer. Presumably, uptake by plankton in inshore areas effected low concentrations of dissolved phosphorus. Total counts of phytoplankton (Figures 1 through 7) ranged from 1,000-5,000 per ml at many of the stations one, four, seven and 10 miles from shore with slightly higher counts along the eastern shore. Beyond 10 miles from shore the densities of phytoplankton diminished greatly. Counts in this middle area of the lake were rarely more than 500 per ml. Tables 1 and 2 present phytoplankton data by the number of stations at which ranges of values occurred. Ranges of phytoplankton densities in counts per ml for sampling periods between April and November are as follows:

Sampling Period	Inshore - 1-10 miles	Beyond 10 miles
April 24 - May 7	198 - 4,788	165 - 900
June 5 - June 18	352 - 1,067	98 - 440
July 17 - July 30	33 - 1,428	28 - 385
August 29 - September 9	33 - 1,034	No Samples
October 9 - October 23	42 - 2,086	No Samples
October 18 - November 30	88 - 6,182	No Samples
October 28 - December 4	44 - 1,474	44 - 264

Although total counts of phytoplankton in the 1,000-5,000 per ml ranges indicate relatively high biological productivity, the kinds of algae present are equally important. The diatoms Melosira, Cyclotella, and Stephanodiscus, which are common inhabitants of nutrient-enriched waters were the genera that predominated samples from Milwaukee Harbor and most of the shoreline stations from Milwaukee to Chicago (Table 2). Along the Michigan shoreline, Cyclotella-Stephanodiscus predominated and Melosira were numerous in many samples.

In samples from stations beyond 10 miles, the diatoms Asterionella, Tabellaria, Fragilaria and Synedra were the predominant genera (Table 2). These are the forms that have typified the planktonic algae of Lake Michigan for many years (9). They are also typical of Lake Superior and other oligotrophic lakes, where they dominate the phytoplankton populations. In Lake Superior, however, their numbers are less than those observed in many Lake Michigan samples. Lake Superior averages about 200 per ml in some shoreline areas (3). It is also significant that *Cyclotella* sometimes occurred abundantly in Lake Michigan samples dominated by *Asterionella*, *Fragilaria*, *Tabellaria* and *Synedra*. Table 2 shows that averages of *Cyclotella* were relatively high in all sampling zones.

Benthic Fauna

Only eight different kinds of organisms occurred abundantly, and the amphipods were abundant in all areas of the lake where conditions were favorable. They prefer a habitat of sand or gravel and are not numerous in lake bottoms covered by organic sediments. Their occurrence is summarized in Table 6 as percentages of amphipods to the total number of all benthic fauna.

Table 6 shows that the southeast quadrant, one-mile stations were heavily populated by scuds. Further, nine of the 12 stations in the 0-25% occurrence range shown in the table represent one-mile stations between South Haven and Michigan City where the lake bottom is subject to wave-induced shifting sands that provide a poor habitat for bottom-dwelling organisms. There were no scuds in Milwaukee Harbor and very few in Green Bay.

The Oligochaeta are useful in evaluating the effect of organic influents on the biota of the lake. These small worms prefer a habitat of organic sediment. Table 7 summarizes the occurrence of this group of organisms by percentage of organisms to the total number of bottom-dwelling animals.

The effect of wastes in Milwaukee Harbor is clearly indicated by the number of stations where the oligochaetes constituted 75-100% of the bottom animal populations (Table 7). Values as high as 170,000 per m^2 were observed. More noteworthy is the evidence of large populations of these organisms at the deep-water stations in both the southern and northern basins of the lake. Numbers of oligochaetes ran as high as 1,816 per m^2 of lake bottom at deepwater stations in the northern basin and 2,831 per m^2 in the southern basin. Counts as high as 7,000 per m^2 were found at inshore stations near Benton Harbor and Michigan City.

The relative abundance of oligochaetes and amphipods are shown graphically in Figures 8 and 9 by percentage of each to the total number of organisms. The total number of organisms per square meter of lake bottom is also given. Generally, benthic populations were greater in the southern basin (South of Milwaukee and Muskegon) than in the northern basin. However, there were individual counts as high as 19,000 per m^2 at inshore stations north of Latitude 43°30', and as high as 13,000 per m^2 south of Latitude 42°00'.

The Tendipedidae were not predominant at any of the stations but they were found at about two-thirds of the sampling stations. In some instances they were second to the sludgeworms in abundance and were otherwise the third most numerous organisms found. Fingernail clams and small snails were commmon at many stations.

An earlier study of the benthic fauna of Lake Michigan was made in 1931 and 1932 by Eggleton (18), (19). The results of that study and others in Lake Huron (20) and two Canadian lakes(14) provide information that reveals the changing character of Lake Michigan fauna. The Canadian lakes are included in the comparisons because one (Lake Athabasca) is a very oligotrophic lake and the other (Churchill Lake) is eutrophic. Both are in a remote area where effects due to human habitation have been negligible.

A comparison of percentages of the number of amphipods and oligochaetes reveal some interesting trophic features of these lakes, but more important are the comparisons of the fauna of Lake Michigan in 1931 and 1962. The percentages of organisms, the average number of organisms, and the highest number found in each lake are shown below.

Lake	Year	% Amphipoda	% Oligochaeta	% Other	Ave. No/m^2	Max. No/m^2
Churchill	1957	23	9	68	1,076	-
Athabasca	1947	61	12	27	1,275	-
Huron	1952 and 1956	77	9	14	1,461	10,556
Michigan	1931	65	24	11	1,243	10,200
Michigan	1962	48	39	13	4,229	26,257

(Harbor stations not included)

The 68% Other in Churchill Lake and 13% Other in Lake Michigan 1962 were mostly midge larvae (Tendipedidae). The 1931 Lake Michigan study reports that fingernail clams (Sphaeriidae) were third in dominance. The change in species dominance and the increased populations of organisms are probably due to a change in habitat caused by organic sedimentation.

Organic Matter

The organic matter in a half-meter-diameter column of water at each sampling station is summarized in Table 5. In both the southeast and southwest quadrants the pattern of concentrations follows very closely those for phytoplankton counts where generally the plankton was at its highest density near the shoreline and diminished at stations farther from shore. In the 0-25 mg/m^3 range of Table 5, proportionately more occurrences are recorded for the southeast quadrant where 37 of 57 were in that range. In the southwest quadrant 24 out of 111 plankton tows were within the 0-25 mg/m^3 range, and values range from 26-200 mg/m^3 at 87 stations.

The northern basin was not sampled extensively but results from 9 of the 10 stations indicated low concentrations of organic matter. Only one was in the 76-100 mg/m^3 range.

Light Penetration

Light penetration deeper than 12 meters was observed at three stations in the southern basin and three stations in the northern basin. The deepest light penetration was 18 meters found at one station centrally located in the northern basin. The lowest values were less than one meter in Milwaukee Harbor. In the lake proper the lowest values were 1 mile at stations off Gary, Indiana. There was considerable difference in light penetrations at the inshore and mid-lake sampling areas. This is clearly indicated by the large number of inshore stations where values were less than 6 meters (Table 8). Penetration less than 2 meters was observed at 21 stations in the southwest quadrant. Most of those low readings were at stations on the one-mile contour along the Wisconsin and Indiana shores. Phytoplankton samples taken at the same time produced high counts along the Wisconsin shore and low counts along the Indiana shore. Apparently, waste discharges in the Indiana area were responsible for high turbidities and resultant low biological activity.

CHICAGO BEACH ALGAL PROBLEM

The Chicago Park District has reported cases of beaches being fouled with algae washed in from the lake for several years. On August 27, 1961 and on August 16, 1962, Great Lakes-Illinois River Basins Project biologists investigated occurrences at Oak Street and Montrose beaches. In 1961 the offending organism was found to be Dichotomosiphon, a green filamentous alga similar in appearance to Cladophora. Rhizoclonium and Cladophora were also present. In 1962 Cladophora was the principal alga but Oedogonium was also present intermixed with the Cladophora. All of these organisms require a hard substratum, or attachment surface. The windrows of algae that completely lined the beaches became foul-smelling after a few days exposure to the summer heat. Flies and other insects covered the decaying masses.

Project biologists also examined filamentous algal growths on boats, breakwaters, buoys, and in harbors from Burns Ditch, Indiana to Green Bay, Wisconsin. They found that practically any submerged solid provides a surface for the growth of algae. Since the nutritional requirements of the filamentous algae are similar to the other algae (12), it is concluded that concentrations of phosphorus, nitrogen, and other nutrients are ample in the shoreline areas of the lake between the southern tip of the lake and Green Bay.

CONCLUSIONS

Local Effects of Waste Discharges

The effects of wastes discharged at Milwaukee afford an excellent opportunity to evaluate the impact on the lake biota in a selected area. Inside the Milwaukee Harbor breakwater both the phytoplankton and benthic fauna were dominated by organisms favoring organic enrichment. The benthic fauna consisted of sludgeworms and scuds did not exist. Milwaukee Harbor is considered biologically degraded. At stations in the vicinity of Milwaukee but outside the breakwater, sludgeworms also predominated but pulmonate snails and leeches were also present. This lake area is also biologically degraded but to a lesser degree.

The dominance of Melosira and Cyclotella in the Milwaukee area of the lake was due to the availability of nutrients. The subsequent persistence of these organisms at many of the one and four mile stations south from Milwaukee to near Chicago is attributed to one or a combination of the following: (1) a lack of mixing with Lake Michigan waters, (2) a transport of nutrients coincidental with the organisms, (3) the addition of nutrients and organisms by waters emanating from Racine, Kenosha, and Waukegan harbors and waste outfalls.

The relatively high total phytoplankton counts of 1,000-5,000 per ml found at many stations along the shoreline is attributed to the warmer waters of the littoral zone and nutrient availability. The slightly greater density on the Michigan shore is probably due to the prevailing westerly winds that cause the water to be warmer on the Michigan side of the lake. The prevailing westerly wind would also hold the plankton-laden water against the eastern shore. In addition, a counterclockwise movement of water in the southern basin (as is suggested by tracing Melosira and Cyclotella from Milwaukee to Chicago) would transport nutrients to the Michigan shoreline.

General Biological Condition of Lake Michigan

The center of Lake Michigan yielded concentrations of phytoplankton in the 0-500 per ml range, and light penetration was generally more than 6 meters. The flora (predominated by Synedra, Asterionella and Tabellaria) was similar to the flora of Lake Superior. The middle area of the lake is decidely oligotrophic.

However, the lake waters adjacent to Wisconsin and Michigan harbors were predominated by Melosira and Cyclotella. These genera of algae are not typical of oligotrophic lakes. In addition, the total phytoplankton counts averaged about 1,500 per ml within the ten mile contour, and less than 200 per ml at stations beyond the ten mile contour. In comparison, Lake Superior averages about 200 per ml at shoreline stations and much less at the center of the lake.

The changing character of the benthic fauna is reflected in increased populations of sludgeworms and decreased populations of amphipods in the past 30 years. This has been caused by the continuous sedimentation of organic matter that has gradually altered the habitat to one increasingly more favorable to sludgeworms. As the organic sedimentation continues the benthic fauna will change, and eventually become dominated by organisms typical of a eutrophic lake.

Lake Michigan receives wastes from a number of tributary streams and waste outfalls. From the phytoplankton data it appears that some of those wastes, containing nutrients, do not disperse evenly throughout the lake, but tend to follow the shorelines where they effect quantities and kinds of phytoplankton quite different from oligotrophic lakes.

Further additions of nutrients to the system will certainly result in expansion of the inshore areas where high concentrations of phytoplankton occur. Populations of phytoplankton will increase, first in the lake waters adjacent to the nutrient source, and gradually to other inshore areas.

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TABLE 1 Phytoplankton Densities at the Surface-Lake Michigan
April-December 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Organisms per milliliter at surface Ranges of Values			
		0-500	500-1000	1000-2500	2500-5000
Southeast Quadrant:					
1 mile offshore	34	17	11	4	2
4 miles offshore	22	19	1	1	1
7 miles offshore	14	12	2	0	0
10 miles offshore	11	11	0	0	0
Beyond 10 miles	13	10	3	0	0
Southwest Quadrant:					
1 mile offshore	40	24	9	7	0
4 miles offshore	54	43	6	4	1
7 miles offshore	22	21	1	0	0
10 miles offshore	25	23	1	1	0
Beyond 10 miles	24	23	1	0	0
Milwaukee Harbor and Vicinity:					
inside breakwater	32	0	1	7	24
outside breakwater	38	26	10	2	0
Chicago Harbor:	13	7	5	1	0
Northern Basin:					
1 mile offshore	14	7	5	1	1
4 miles offshore	11	6	3	1	1
7 miles offshore	0	-	-	-	-
10 miles offshore	0	-	-	-	-
Beyond 10 miles	19	17	2	0	0
Green Bay:	6	3	3	0	0

TABLE 2 Densities of the Predominant Genera of Phytoplankton at the Surface
Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Southeast Quadrant:									
1 mile offshore	min.	42	0	0	0	0	0	0	42
	max.	1876	280	1288	84	154	84	1512	4732
	ave.	409	27	101	14	28	15	201	795
4 miles offshore	min.	0	0	0	0	0	0	11	33
	max.	588	56	464	33	112	28	1820	3108
	ave.	107	6	38	13	17	20	178	379
7 miles offshore	min.	0	0	0	0	0	0	11	70
	max.	352	44	451	44	66	55	264	990
	ave.	73	6	57	8	10	4	73	231
10 miles offshore	min.	0	0	0	0	0	0	0	42
	max.	70	11	22	14	11	14	82	196
	ave.	42	2	3	1	1	4	44	97
beyond 10 miles	min.	0	0	0	0	0	0	0	66
	max.	242	50	350	33	75	100	220	638
	ave.	85	5	74	10	19	13	70	276
Southwest Quadrant:									
1 mile offshore	min.	0	0	0	0	0	0	0	33
	max.	308	1584	220	154	638	264	832	2112
	ave.	103	57	43	30	121	81	137	572

Table 2 (continued)
Densities of the Predominant Genera of Phytoplankton at the Surface
Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
4 miles offshore	min.	0	0	0	0	0	0	11	33
	max.	1100	242	224	154	462	374	330	2552
	ave.	134	15	28	26	58	43	93	397
7 miles offshore	min.	11	0	0	0	0	0	0	110
	max.	462	11	44	77	110	99	209	550
	ave.	100	2	13	21	30	35	51	252
10 miles offshore	min.	0	0	0	0	0	0	0	77
	max.	406	22	728	66	176	110	320	1298
	ave.	100	2	41	18	33	24	67	285
beyond 10 miles	min.	0	0	0	0	0	0	0	28
	max.	168	33	209	112	364	44	196	854
	ave.	51	3	60	11	29	12	61	227
Milwaukee Harbor:									
inside breakwater	min.	110	198	0	0	11	22	55	770
	max.	1298	2948	132	176	374	396	840	4778
	ave.	586	1900	43	42	105	197	265	3138
outside breakwater north of harbor entrance	min.	22	0	0	0	0	0	11	154
	max.	132	308	44	44	44	88	198	726
	ave.	49	47	15	16	25	52	52	256

Table 2 (continued)
Densities of the Predominant Genera of Phytoplankton at the Surface
Lake Michigan, April-December, 1962

Sampling Zone		Organisms per Milliliter							
		Cyclo-Steph	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
outside breakwater south of harbor entrance	min.	11	0	0	0	0	0	0	154
	max.	1188	3960	77	66	220	264	440	6182
	ave.	127	356	28	19	44	73	64	711
Chicago Harbor: Northern Basin:	min.	11	0	0	0	44	33	22	154
	max.	220	66	66	110	286	286	198	1078
	ave.	105	18	33	30	120	163	86	556
1 mile offshore	min.	0	0	22	0	0	0	44	132
	max.	1456	132	572	56	88	70	280	3052
	ave.	178	6	266	18	44	20	151	683
4 miles offshore	min.	0	0	11	0	0	0	56	154
	max.	308	84	682	44	56	33	2856	3668
	ave.	95	9	254	14	19	5	374	770
beyond 10 miles	min.	0	0	0	0	0	0	0	56
	max.	242	44	176	33	33	28	462	770
	ave.	55	10	96	7	8	4	100	280
Green Bay:									
	min.	11	0	0	11	0	22	11	209
	max.	99	22	638	55	33	286	242	968
	ave.	46	9	209	33	11	116	139	563

TABLE 3 Phytoplankton Densities at 50 Meters or Deeper
Lake Michigan, April-December 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Organisms per Milliliter — Ranges of Values: 0 - 500	500 - 1000	1000 - 2500	2500 - 5000
Southeast Quadrant:					
1 mile offshore	1	1	0	0	0
4 miles offshore	0	-	-	-	-
7 miles offshore	7	6	1	0	0
10 miles offshore	5	5	0	0	0
Beyond 10 miles	10	10	0	0	0
Southwest Quadrant:					
1 mile offshore	0	-	-	-	-
4 miles offshore	0	-	-	-	-
7 miles offshore	2	2	0	0	0
10 miles offshore	5	5	0	0	0
Beyond 10 miles	19	19	0	0	0
Northern Basin:					
1 mile offshore	1	1	0	0	0
4 miles offshore	4	2	2	0	0
7 miles offshore	0	-	-	-	-
10 miles offshore	1	1	0	0	0
Beyond 10 miles	17	17	0	0	0

Table 4 Densities of the Predominant Genera of Phytoplankton

Lake Michigan, April-December, 1962

Sampling Zone	No. of Stations		Organisms per Milliliter at 50 Meters or Deeper							
			Cyclo.-Steph.	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Southeast Quadrant:										
1 mile offshore	1	Min.	11	0	88	33	0	11	11	154
		Max.	11	0	88	33	0	11	11	154
		Ave.	11	0	88	33	0	11	11	154
7 miles offshore	7	Min.	0	0	0	0	0	0	0	55
		Max.	132	66	110	88	88	44	110	528
		Ave.	64	17	41	25	33	19	25	224
10 miles offshore	5	Min.	33	0	11	0	0	0	0	66
		Max.	66	11	33	11	44	11	44	154
		Ave.	51	2	24	2	18	2	9	108
Beyond 10 miles	10	Min.	0	0	0	0	0	0	0	55
		Max.	132	198	33	66	44	0	110	440
		Ave.	42	50	10	17	10	0	33	162
Southwest Quadrant:										
7 miles offshore	2	Min.	33	0	0	11	55	0	0	110
		Max.	33	0	0	55	110	22	77	275
		Ave.	33	0	0	33	83	11	39	199
10 miles offshore	5	Min.	11	0	0	0	0	0	0	44
		Max.	44	11	22	22	44	22	88	198
		Ave.	22	2	11	11	22	9	33	110

Table 4 (Continued) Densities of the Predominant Genera of Phytoplankton

Lake Michigan, April-December, 1962

			Organisms per Milliliter at 50 Meters or Deeper							
Sampling Zone	No. of Stations		Cyclo.-Steph.	Melosira	Synedra	Fragilaria	Tabellaria	Asterionella	Other	All Genera
Beyond 10 miles	19	Min.	0	0	0	0	0	0	0	33
		Max.	110	44	132	33	44	33	88	:286
		Ave.	39	6	30	9	10	5	25	125
Northern Basin:										
1 mile offshore	1	Min.	66	0	88	0	44	0	110	308
		Max.	66	0	88	0	44	0	110	308
		Ave.	66	0	88	0	44	0	110	308
4 Miles offshore	4	Min.	22	0	44	0	0	0	22	308
		Max.	176	44	506	44	154	66	110	880
		Ave.	83	22	259	11	72	33	66	534
10 miles offshore	1	Min.	99	22	77	0	33	0	33	264
		Max.	99	22	77	0	33	0	33	264
		Ave.	99	22	77	0	33	0	33	264
Beyond 10 miles	17	Min	0	0	0	0	0	0	0	11
		Max.	66	55	132	44	66	22	66	352
		Ave.	19	15	30	6	16	4	16	106

Table 5 Organic Matter (Loss due to ignition) in Vertical Plankton Tows

Lake Michigan, July-December, 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Organic Matter in mg/m^3 — Ranges of Values: 0-25	26-50	51-75	76-100	101-200	Remarks
Southeast Quadrant:							
1 mile offshore	23	8	8	3	3	1	Highest Value – 275 mg/m^3 at a one mile station near Wilmette
4 miles offshore	10	6	4	0	0	0	
7 miles offshore	9	9	0	0	0	0	
10 miles offshore	7	6	1	0	0	0	
Beyond 10 miles	8	8	0	0	0	0	
Southwest Quadrant:							
1 mile offshore	28	1	5	5	5	12	
4 miles offshore	32	2	7	10	8	5	
7 miles offshore	17	4	6	3	2	2	
10 miles offshore	16	5	3	5	1	2	
Beyond 10 miles	18	12	4	2	0	0	
Milwaukee Harbor and Vicinity:	31	1	11	9	6	5	
Chicago Harbor:	15	0	0	0	1	14	
Northern Basin:	10	7	2	0	1	0	

Table 6 Amphipod (Scuds) Populations, Lake Michigan
April-December 1962

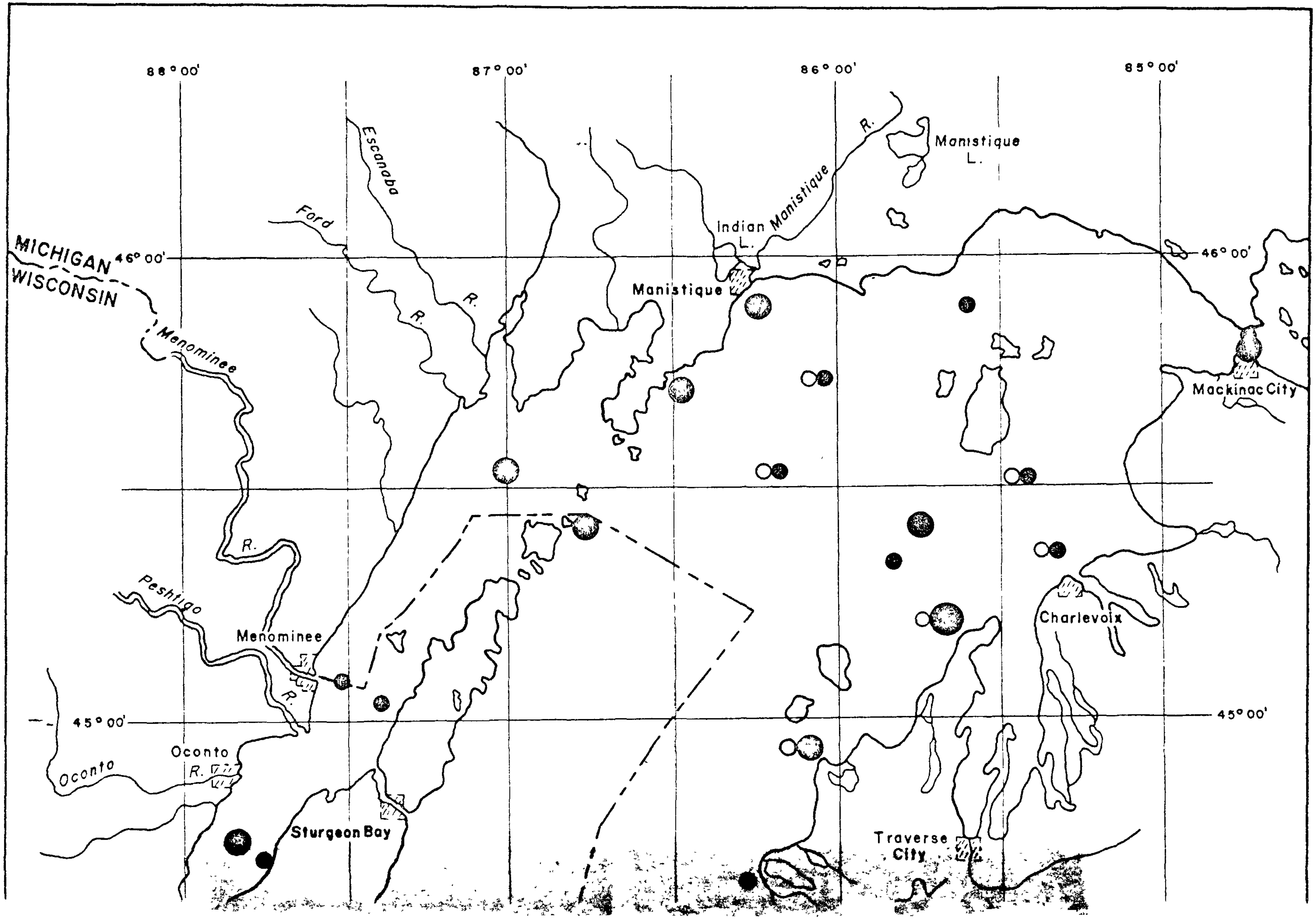
Sampling Zone	No. of Stations	Frequency of Occurrence Percent of Amphipods to Total Number — Ranges of Values: 0-25	26-50	51-75	76-100	Remarks
Southeast Quadrant:						
1 mile offshore	32	12	2	9	9	9 of the 0-25% stations were subject to wave action.
4 miles offshore	20	3	5	8	4	
7 miles offshore	14	1	5	7	1	
10 miles offshore	10	2	4	4	0	
Beyond 10 miles	10	1	4	5	0	
Southwest Quadrant:						
1 mile offshore	4	1	0	2	1	midge larve also abundant at 7 and 10 mile stations
4 miles offshore	7	2	2	3	0	
7 miles offshore	8	3	1	3	1	
10 miles offshore	6	2	1	2	1	
Beyond 10 miles	16	0	9	5	2	
Milwaukee Harbor and Vicinity:	7	7	0	0	0	No Amphipods in Milwaukee Harbor
Northern Basin:						
1 mile offshore	13	5	3	2	3	
4 miles offshore	10	4	2	2	2	
7 miles offshore	0	-	-	-	-	
10 miles offshore	0	-	-	-	-	
Beyond 10 miles	22	4	7	9	2	
Green Bay:	6	2	4	0	0	

TABLE 7 Oligochaeta (Sludgeworms) Populations, Lake Michigan
April-December, 1962

Sampling Zone	No. of Stations	Frequency of Occurrence — Percent of Oligochaeta to Total Number — Ranges of Values: 0 - 25	26 - 50	51 - 75	76 - 100	Remarks
Southeast Quadrant:						
1 mile offshore	32	18	7	4	3	9 of the 0 - 25 stations were subject to wave action
4 miles offshore	20	8	5	6	1	
7 miles offshore	14	1	9	4	0	
10 miles offshore	10	0	5	3	2	
Beyond 10 miles	10	1	6	3	0	
Southwest Quadrant:						
1 mile offshore	4	2	1	1	0	
4 miles offshore	7	1	3	2	1	
7 miles offshore	8	1	5	0	2	
10 miles offshore	6	2	2	1	1	
Beyond 10 miles	16	4	7	5	0	
Milwaukee Harbor and Vicinity	7	1	1	0	5	Oligochaetes dominant
Northern Basin:						
1 mile offshore	13	8	3	2	0	
4 miles offshore	10	4	2	3	1	
7 miles offshore						
10 miles offshore						
Beyond 10 miles	22	5	11	3	3	
Green Bay:	6	3	1	0	2	

TABLE 8 Light Penetration (Secchi Disc), Lake Michigan
April-December, 1962

Sampling Zone	No. of Stations	Frequency of Occurrence Transparency in Meters, Ranges of Values: 0 - 2	2.1 - 6	6.1 - 12	12.1 - 20
Southeast Quadrant:					
1 mile offshore	38	1	34	3	0
4 miles offshore	19	1	15	3	0
7 miles offshore	15	1	8	7	0
10 miles offshore	11	0	3	8	0
Beyond 10 miles	10	0	5	5	0
Southwest Quadrant:					
1 mile offshore	57	19	38	0	0
4 miles offshore	52	2	47	3	0
7 miles offshore	23	0	16	7	0
10 miles offshore	27	0	22	5	0
Beyond 10 miles	32	0	8	21	3
Milwaukee Harbor and Vicinity:					
inside breakwater	33	33	0	0	0
outside breakwater	44	16	28	0	0
Chicago Harbor:	17	10	7	0	0
Northern Basin:					
1 mile offshore	10	1	9	0	0
4 miles offshore	10	0	5	4	1
Beyond 10 miles	16	0	2	12	2
Green Bay:	6	0	6	0	0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45° 00'
MICHIGAN
WISCONSIN
Menominee
R.
Peshtigo
Menominee
R.
Oconto
Oconto
R.
Sturgeon Bay
Ford
R.
Escanaba
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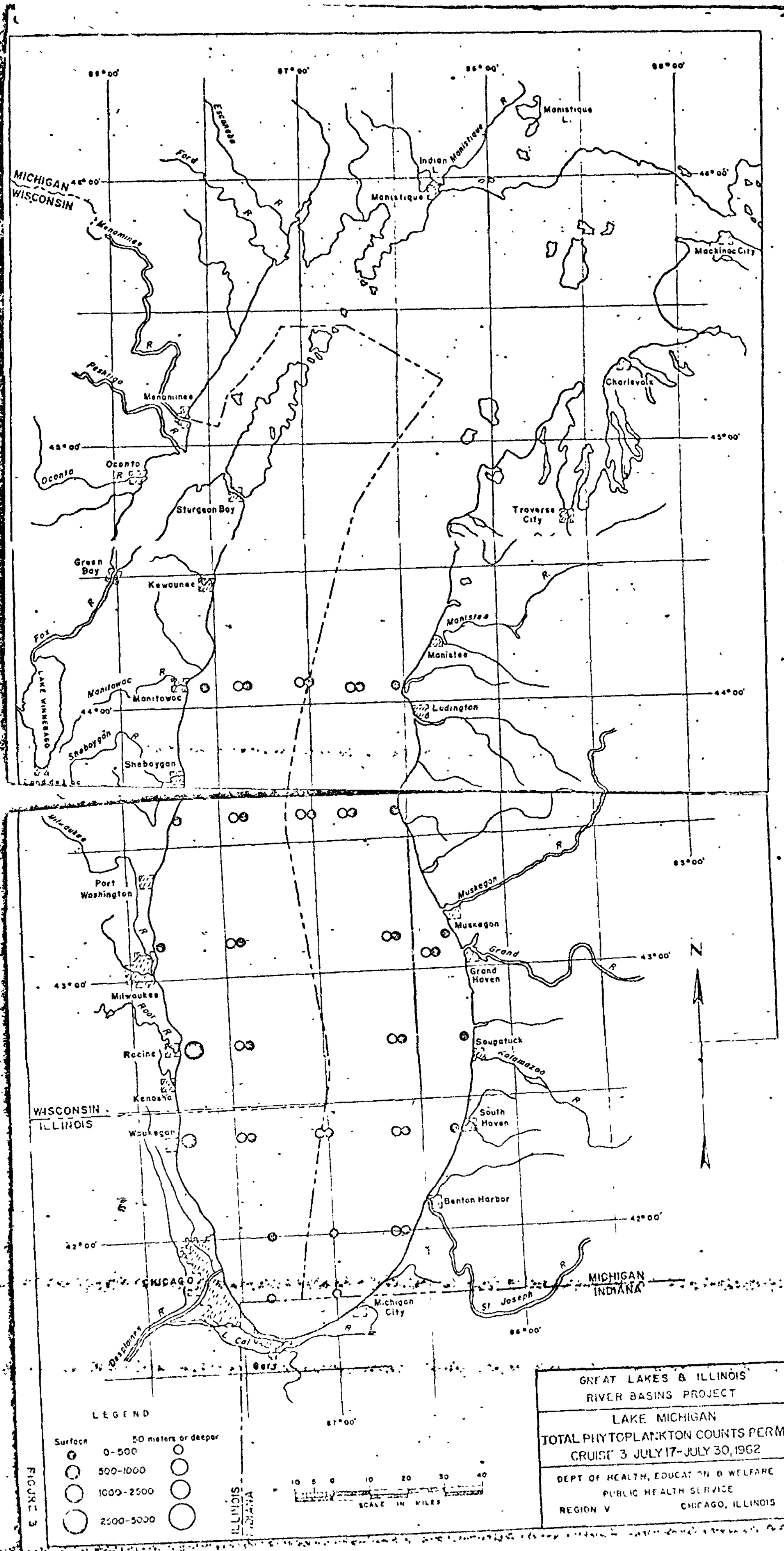
Indian
L.
Manistique
Manistique
R.
Manistique
L.
Mackinac City
Charlevoix
Traverse
City



GREAT LAKES & ILLINOIS RIVER BASINS PROJECT

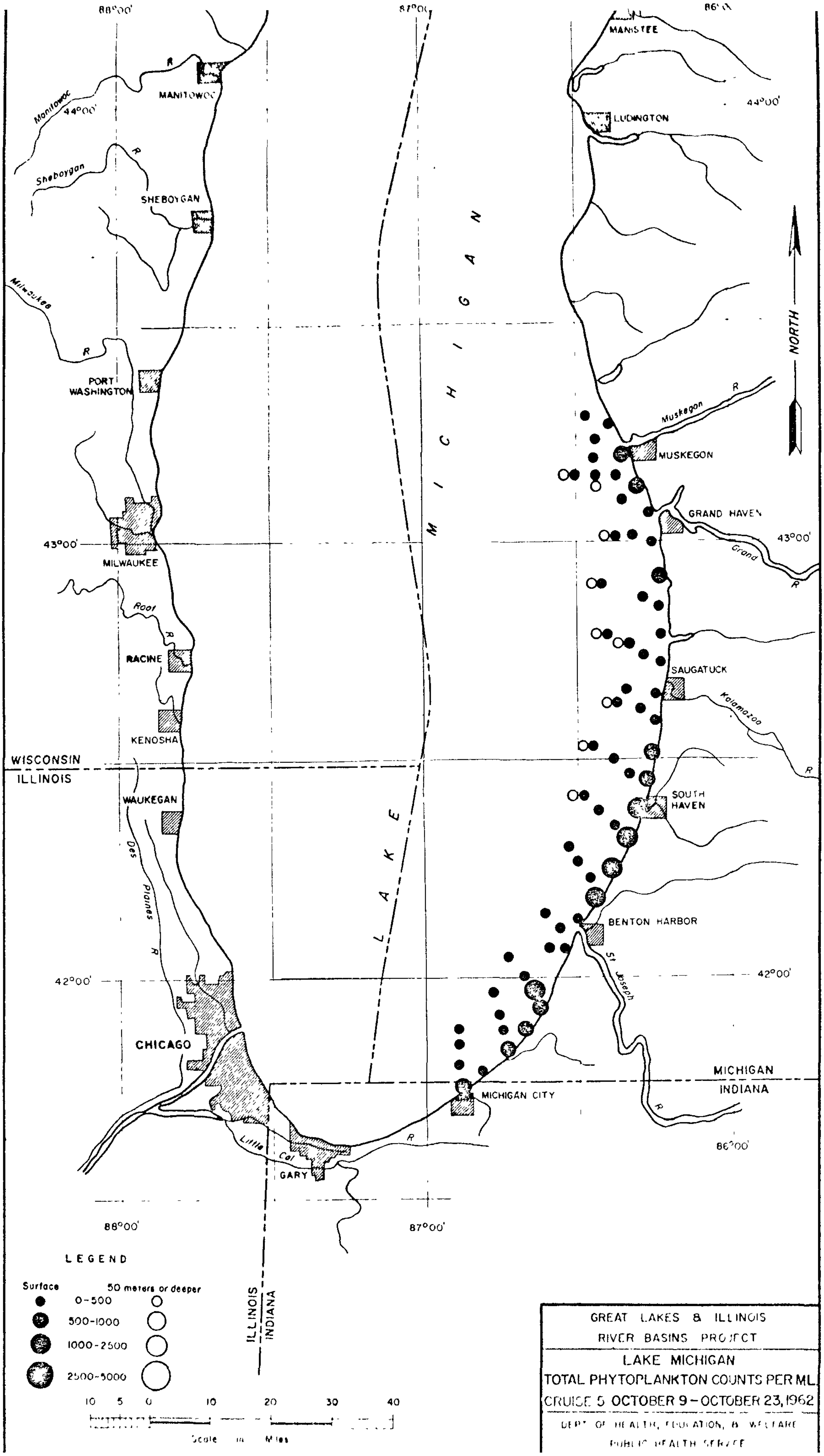
LAKE MICHIGAN

TOTAL PHYTOPLANKTON COUNTS PER ML

CRUISE 3 JULY 17-JULY 30, 1962

DEPT OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION V CHICAGO, ILLINOIS

FIGURE 3


GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML.
CRUISE 5 OCTOBER 9 – OCTOBER 23, 1962
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000-2500
2500-5000
Scale in Miles
10 5 0 10 20 30 40
LAKE MICHIGAN
NORTH
WISCONSIN
ILLINOIS
ILLINOIS
INDIANA
MICHIGAN
INDIANA
MANITOWOC
SHEBOYGAN
PORT WASHINGTON
MILWAUKEE
RACINE
KENOSHA
WAUKEGAN
CHICAGO
GARY
MICHIGAN CITY
BENTON HARBOR
SOUTH HAVEN
SAUGATUCK
GRAND HAVEN
MUSKEGON
LUDINGTON
MANISTEE
Manitowoc R
Sheboygan R
Milwaukee R
Root R
Des Plaines R
Little Cal R
St Joseph R
Kalamazoo R
Grand R
Muskegon R
88°00'
87°00'
86°00'
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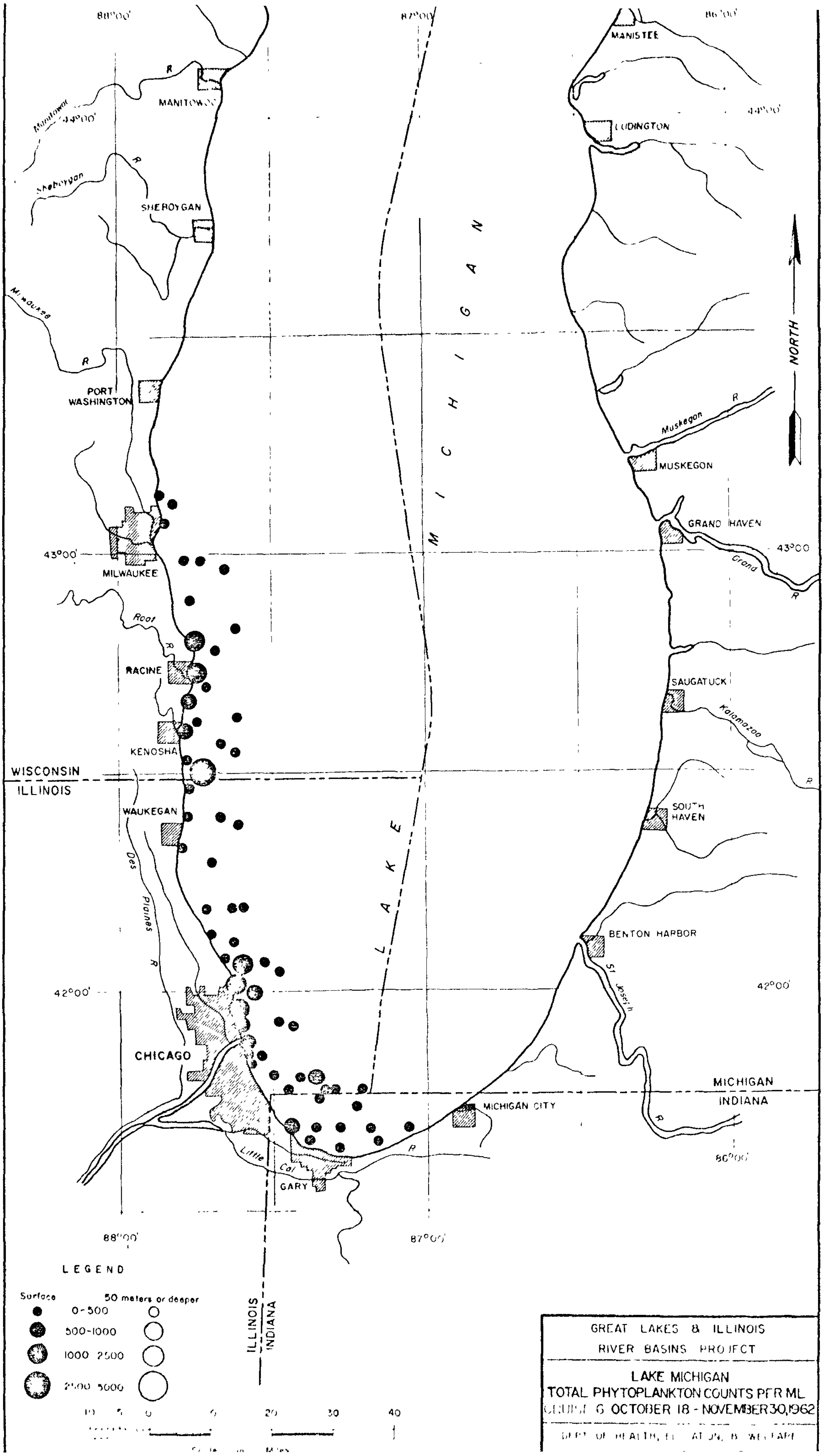
43°00'
42°00'

FIGURE 5


88°00'
87°00'
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MANISTEE
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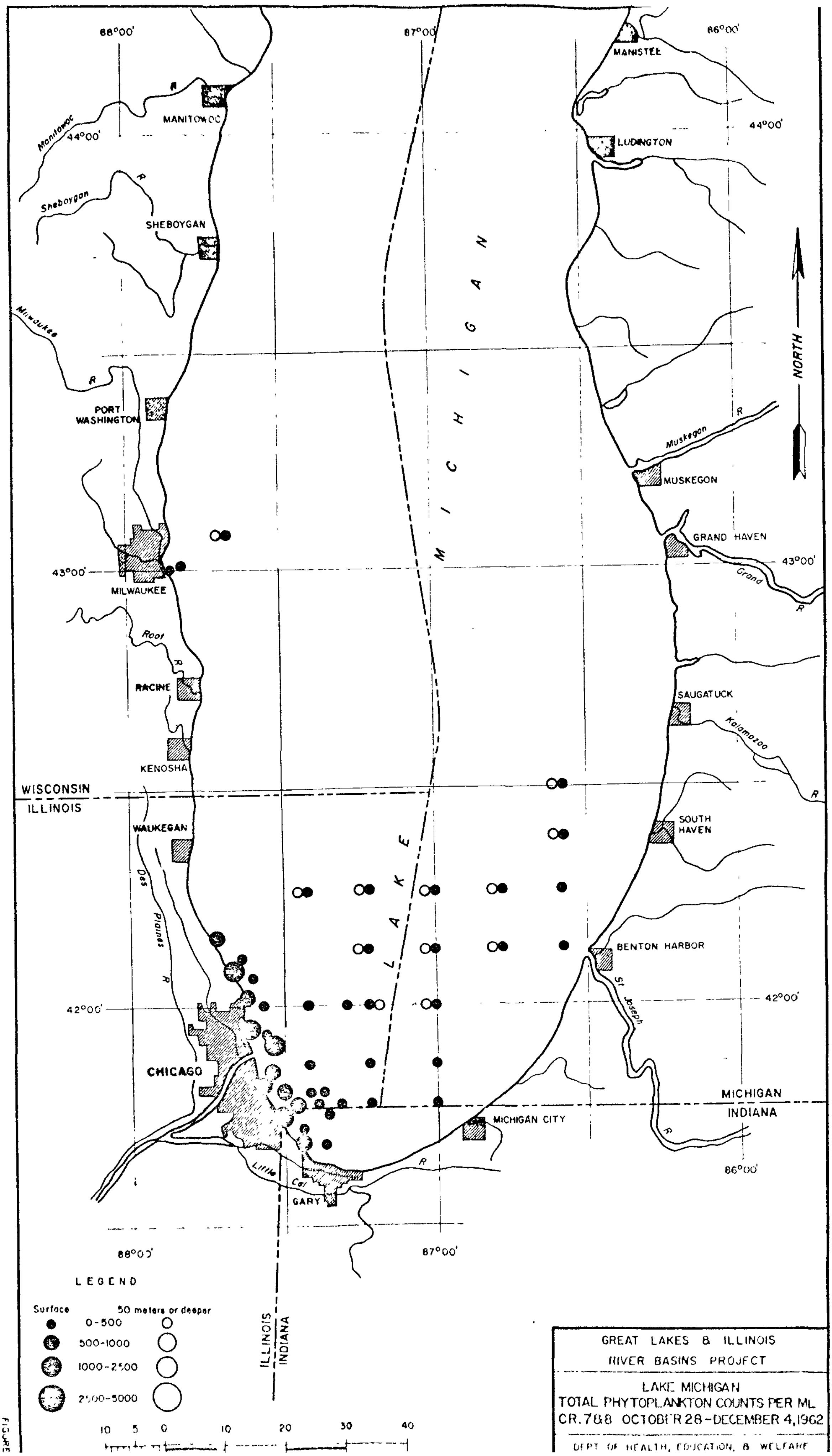
LUDINGTON
Sheboygan R
SHEBOYGAN
Milwaukee R
PORT WASHINGTON
NORTH
Muskegon R
MUSKEGON
GRAND HAVEN
LAKE MICHIGAN
43°00'
MILWAUKEE
Grand R
Root R
RACINE
SAUGATUCK
Kalamazoo R
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
SOUTH HAVEN
Des Plaines R
BENTON HARBOR
St Joseph R
42°00'
CHICAGO
MICHIGAN
INDIANA
MICHIGAN CITY
Little Cal R
GARY
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000 2500
2500 5000
ILLINOIS
INDIANA
10 5 0 10 20 30 40
Scale in Miles
GREAT LAKES & ILLINOIS
RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML
CRUISE G OCTOBER 18 - NOVEMBER 30, 1962
DEPT OF HEALTH, EDUCATION, & WELFARE



MANISTEE
MANITOWOC
Manitowoc R
44°00'
Sheboygan R
SHEBOYGAN
LUDINGTON
Milwaukee R
PORT WASHINGTON
Muskegon R
MUSKEGON
GRAND HAVEN
43°00'
MILWAUKEE
Grand R
Root R
RACINE
SAUGATUCK
Kalamazoo R
KENOSHA
WISCONSIN
ILLINOIS
WAUKEGAN
SOUTH HAVEN
Des Plaines R
BENTON HARBOR
St Joseph R
42°00'
CHICAGO
MICHIGAN
INDIANA
MICHIGAN CITY
Little Cal R
GARY
88°00'
87°00'
86°00'
LAKE MICHIGAN
NORTH
LEGEND
Surface
50 meters or deeper
0-500
500-1000
1000-2500
2500-5000
ILLINOIS
INDIANA
10 5 0 10 20 30 40
GREAT LAKES & ILLINOIS RIVER BASINS PROJECT
LAKE MICHIGAN
TOTAL PHYTOPLANKTON COUNTS PER ML
CR. 7&8 OCTOBER 28 - DECEMBER 4, 1962
DEPT OF HEALTH, EDUCATION, & WELFARE

FIGURE 7