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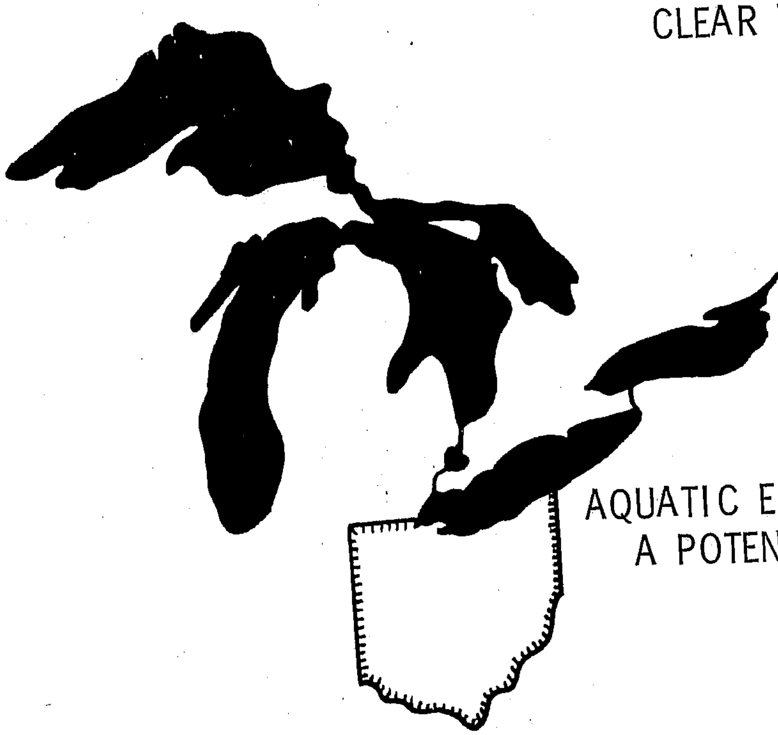

AQUATIC ECOLOGY INVESTIGATIONS OF A POTENTIAL POWER PLANT SITE ON SANDUSKY BAY

FINAL REPORT

Prepared for

American Electric Power Service Corporation
Environmental Engineering Division
and
Ohio Power Company
Canton, Ohio

CENTER FOR LAKE ERIE AREA RESEARCH
THE OHIO STATE UNIVERSITY
COLUMBUS, OHIO

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RESEARCH PERSONNEL

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Donald H. Davis - Field Sampling and Water Quality Monitoring

James E. Voegle - Hydrologic Measurements

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

INTRODUCTION

The purpose of the project, of which this study is a part, was to determine the feasibility of locating a power plant on Sandusky Bay. Physical, chemical and biological parameters were measured over a 2 year period to aid in that determination. The objective of this study is to present a synthesis of these data.

The study began in November, 1972 and concluded in November, 1974. The data collected includes measurements of: depth, transparency, temperature, conductivity, dissolved oxygen, turbidity, pH, total alkalinity, silica, orthophosphate, nitrate nitrogen, carbon dioxide, biochemical oxygen demand, total coliform, fecal coliform, plankton, benthos, and fish. In addition, information from the literature was used to provide data for parameters not measured or characteristics not included as a part of this study.

Historically, Sandusky Bay has been the site of many investigations. Moseley (1899, 1903) was among the first. He was interested in the flora and currents of Sandusky Bay. Klippart (1877) described the fish of Sandusky Bay and Kellicott (1896, 1897) studied the rotifera. Both Burr (1901) and Riddle (1902) studied the plants of Sandusky Bay. A second surge of studies on Sandusky Bay began in 1938 with a limnological survey by Chandler and Bodenlos. This project was followed by and associated with Edminster's masters thesis (1940). Pincus, et al. studied the sediments in Sandusky Bay (1951). Chapman (1955) did a very extensive study of the fish population of Sandusky Bay. Trautman (1957) set the stage with his work on the distribution of the fishes of Ohio with many special references to Sandusky Bay. Price (1963) and Tubb (1973) studied food habits of Sandusky Bay fish.

Field and laboratory data from this investigation have been summarized in three appendixes. These appendixes have been bound separately and consist of the following subjects:

APPENDIX A	Hydrological and Physicochemical Water Quality Data
APPENDIX B	Plankton and Benthos Data
APPENDIX C	Fish and Ichthyoplankton Data

METHODS

Study Area

The locations of the sampling stations are shown in Figures 1 and 2. There are a total of 32 stations in the south bay area, one station on the north side and a transect from the mouth of the Sandusky River to the mouth of Sandusky Bay consisting of seven stations.

Sampling Dates

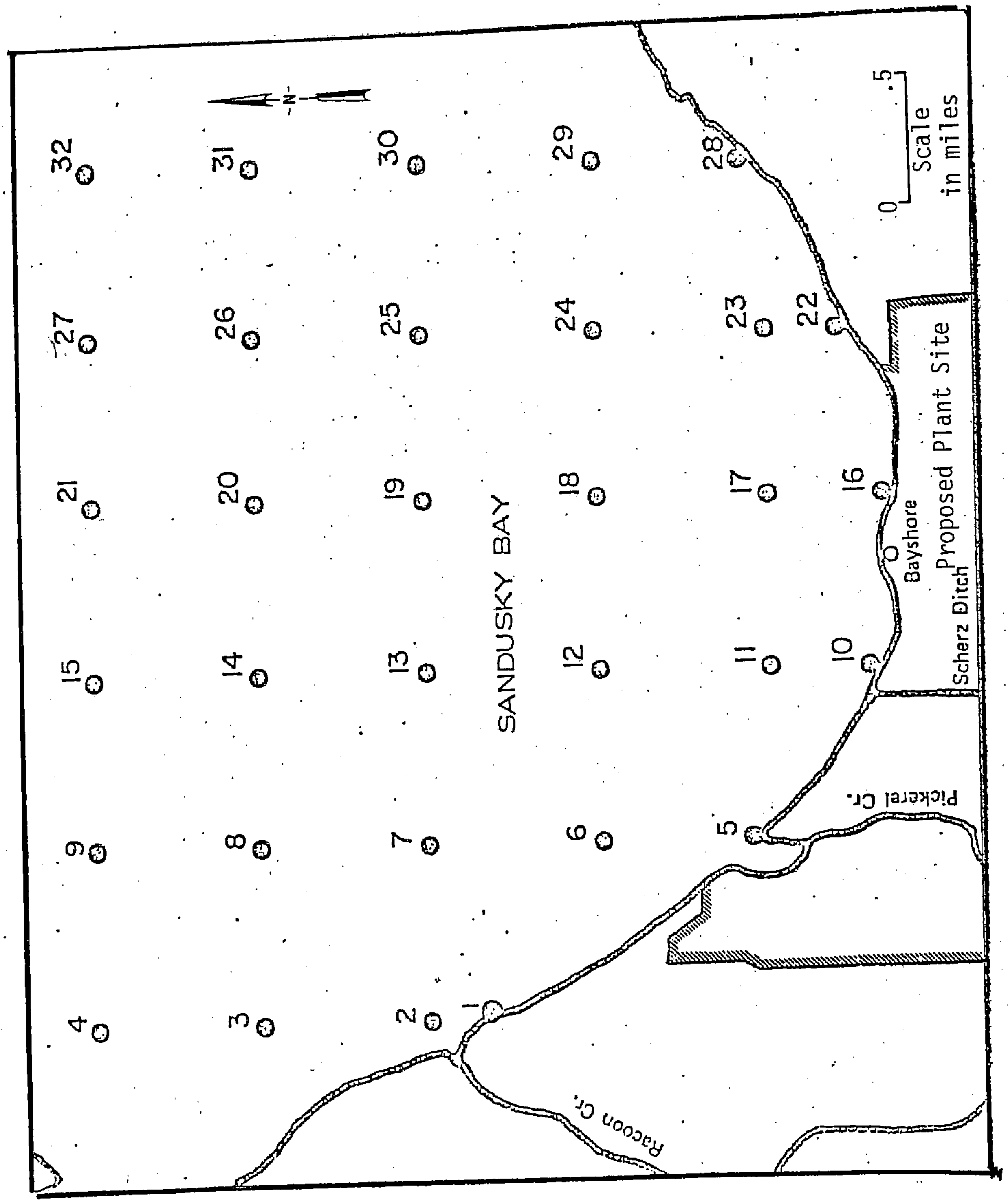
Sampling began in November, 1972, as a preliminary to the sampling program for 1973. Fish, benthos, and physical-chemical parameters were measured in November, 1972. Sampling of all parameters began in March, 1973. Fish samples were taken May thru September, 1973 and April thru November, 1974 (excluding September). Coliform bacteria were measured in July, October, and November of 1973. Benthos was sampled from March thru November of 1973 and January, March thru August and October of 1974. Phytoplankton and zooplankton were sampled March, May thru October, 1973 and January and March thru October, 1974. Food habits anaylsis of various fish species was performed on fish caught in 1974. Chemical-physical parameters were measured November, 1972; May-November, 1973; and April-November, 1974. Sampling dates are summarized in Table 1.

Sampling Procedures

Plankton. Plankton and periphytic diatom surveys of Sandusky Bay were conducted to assess both qualitative and quantitative aspects of these communities. Separate methods were used to evaluate plankton and periphytic diatoms. An

FIGURE 1. SANDUSKY BAY SAMPLING

STATIONS ADJACENT TO PROPOSED POWER PLANT SITE



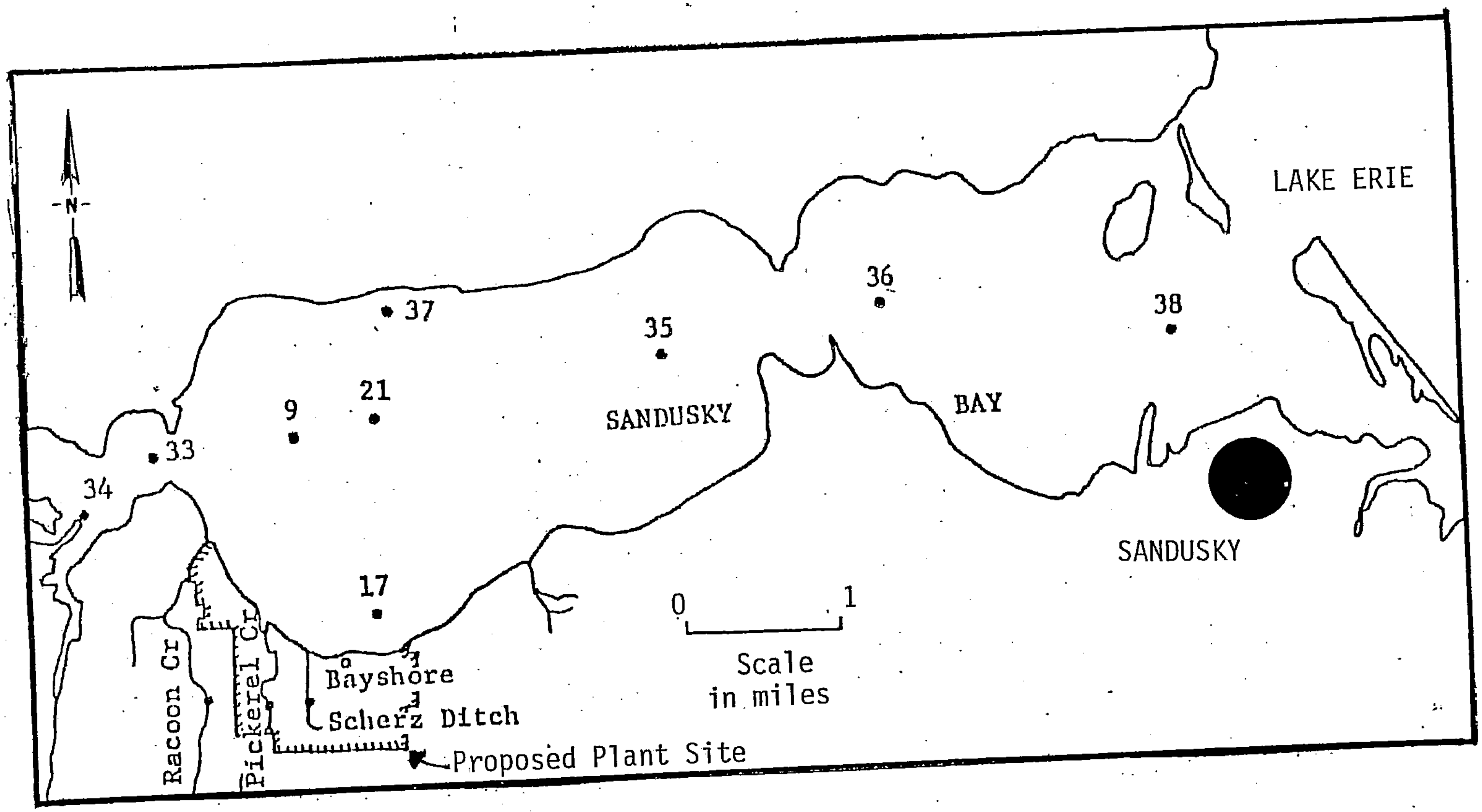


FIGURE 2. POSITION OF SAMPLING STATIONS IN SANDUSKY BAY

TABLE 1

SAMPLING DATES

Field Activity	1972 N	1973 J	F	M	A	M	J	J	A	S	O	N	D	1974 J	F	M	A	M	J	J	A	S	O	N	D
Fry Net																		X	X	X	X		X	X	
Fyke Net	X					X	X	X	X	X															
Seine	X					X	X																		
Trawl																	X	X	X	X	X		X	X	
Gill Net						X	X	X	X	X								X	X	X	X		X	X	
Coliform Bacteria								X			X	X													
Benthos	X		X	X		X	X	X	X	X	X	X		X		X	X	X	X	X	X		X		
Phytoplankton				X		X	X	X	X	X	X			X		X	X	X	X	X	X	X	X		
Zooplankton				X		X	X	X	X	X	X			X		X	X	X	X	X	X	X	X		
Food Habits Analysis																	X	X	X	X	X		X	X	
Physical-Chemical Measurements	X			X		X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	

Plankton was collected by means of vertical and 100 foot horizontal tows with a plankton net of number 20 silk bolting cloth. The vertical tows were used for quantitative evaluation while the 100 foot horizontal tows gave a good sample for qualitative work. The collected sample was preserved with 5% commercial formalin in the field and transported to the laboratory for processing. Samples were diluted to a known volume to facilitate counting of heavy samples. A 1.0 ml sample was removed and placed in a Sedgwick-Rafter counting chamber. With a Whipple disc in an ocular lens of a Leitz Dialux microscope, the organisms in 25 random fields were identified and counted at 100xxtotal magnification. Zooplankton was counted by organism; phytoplankton by cells except for filamentous and colonial forms. Organisms were identified to genus and species where possible at this magnification. The numbers of organisms in the 25 random fields were used to compute the number of organisms per liter of lake water at the sampling site.

Plankton samples were also examined for diatoms. A portion of each sample was washed and decanted to remove the formalin preservative, then cleaned by using 30% hydrogen peroxide and potassium dichromate (Van der Werff, 1953). After thorough washing, the cleaned frustules were mounted in Hyrax. Burn mounts of planktonic diatoms were also made by placing material on coverslips, heated to 500°C for 3 hours and mounted in Hyrax.

Mounted diatom samples were then examined with a Leitz Dialus microscope equippped with 10X periplan, widefield oculars, a 100X 1.30N.A. oil immersion objective lens, and a 0.90N.A. condenser.

Periphytic diatoms were collected on artificial substrates of glass slides in diatometers. The diatoms were removed from the slides by scraping with the sharpened wide end of a toothpick to minimize breakage of frustules. The samples were then cleaned using the aforementioned method of Van der Werff and mounted in Hyrax.

From examination of diatom samples under 1000X, species and variety identification were made of the taxa encountered.

Benthos. Benthic organisms were collected with a 9 x 9" Ekman Dredge (a few of the November, 1972 samples were collected with a 6 x 6" Ekman). The sample was washed through a No. 40 U.S. Standard Sieve Screen. The material on the screen was then washed into a sample container and preserved with 10% formalin. The organisms were sorted and transferred to 80% ethanol. Chironomids and Oligochaetes were identified as follows:

Oligocheates. Each worm was placed on a separate microscope slide with several drops of a Lactophenol solution called Amen's solution. As necessary, each worm was unkinked and/or straightened as well as possible. A coverslip was then added. If needed, additional Amen's solution was introduced under the coverslip. Each slide was then set aside for at least 48 hours. Amen's solution will not set up, so care was necessary to keep the slide upright at all times. Identification was accomplished using a high power microscope. The magnification range was 100X to 660 X.

Chironomid Larvae. All larvae from a given collection were placed in a numbered container of super-saturated Potassium Hydroxide solution. The larvae remained in this solution for 48 hours. The cleared

cleared larvae were then removed from the KOH and washed with several changes of water. The washed larvae were then transferred to a shallow culture dish with water. Using needle-point forceps and a dissecting microscope, the head from each larva was removed. Each head was then transferred to a microscope slide with Hoyer's solution of sufficient volume to fill out the area under a 22 mm square coverslip. Each slide could accomodate about 12 larvae heads. The slide was then placed under the dissecting scope. Using a micro-point probe, each head was adjusted so as to have ventral surface up. A coverslip was then placed on top. Identification was made using a compound microscope. The magnification range was 100x to 660x.

Icthyoplankton. Icthyoplankton nets of number 00 nylon mesh cloth mounted on a 3/4 meter ring were used to capture young fish fry and fish eggs. Horizontal tows of five minutes duration were conducted at the surface and bottom at the following stations: 2, 5, 6, 17 and 20. Icthyoplankton was preserved in formalin and taken to the laboratory for identification.

Fish. Fish were collected by the following methods: 3000-foot commercial seine, 16-foot trawl, 4-foot diameter fyke net, and 125-foot experimental gill net (mesh size in 1973 was 1, 1½, and 2 inches; in 1974 mesh size was ½, 3/4, 1, 1½, and 2 inches). The seine was pulled from an area south of the railroad bridge. The trawl was pulled from station 29 to station 17. The fyke net was set at station 5 during 1973 and was not set in 1974. The experimental gill nets were set at stations 17 and 21 in 1973 and at stations 5 and 17 in 1974. All trawls were five minutes, all gill nets were set for approximately twelve hours.

Fish were identified to species, weighed, and measured. The weights and lengths were not used in this study. In 1974 stomachs were taken from trawled fish. The stomachs were preserved in 10% formalin. Total numbers of food articles were determined by sorting and counting each type of organism. Frequency of occurrence was obtained by counting the number of stomachs in which each type of food item was found. This number is expressed in relation to the total number of fishes found to contain food items. The frequency of occurrence of empty stomachs was also determined.

Physical-Chemical Parameters. The physical and chemical parameters measured are listed in Table 2. Also listed in the table is the method and units.

Microorganisms. Total and fecal coliform bacteria counts were made using the millipore filter technique as described in Standard Methods, 13th Edition (1973).

TABLE 2. WATER QUALITY METHODS

PARAMETER	TABLE 2. UNITS	METHOD
Depth	Meters	Direct Measure
Transparency	Meters	Secchi Disc Depth
Temperature	Degrees Fahrenheit	Reversing Thermometer
Conductivity	Micromhos/Centimeter @ 25°C	Beckmann Conductivity Probe
Dissolved Oxygen	Parts Per Million	Titration, YSI Probe
Turbidity	Jackson Turbidity Units	Turbidimeter
pH	pH Units	pH Meter
Total Alkalinity	Parts Per Million	Titration*
Silica	Parts Per Million	Titration*
Orthophosphate	Parts Per Million	Colorimetry*
Nitrogen-Nitrate	Parts Per Million	Colorimetry*
Carbon Dioxide	Parts Per Million	Titration*
Biochemical Oxygen Demand	Parts Per Million	Titration
Total Coliforms	Organisms/100 milliliters	Millipore Filter
Fecal Coliforms	Organisms/100 milliliters	Millipore Filter

*DR-EL Hach Kit

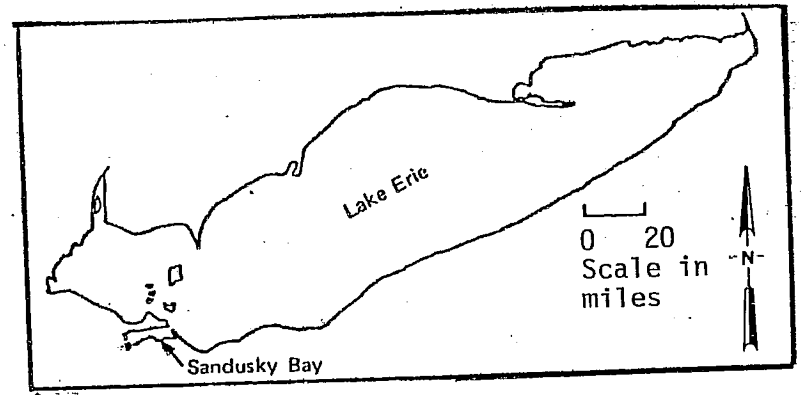
PHYSICAL LIMNOLOGY

Geography

Sandusky Bay is located on the southwestern shore of Lake Erie (Figure 3). It extends into northwestern Ohio on an angle so that the long axis is oriented from the southwest to the northeast. The major tributary is the Sandusky River. Several small streams also flow into the bay. The more significant streams in terms of water flow are Pickerel and Pipe Creeks. The bay is adjacent to Erie, Ottawa and Sandusky counties. Other counties in the watershed are listed in Table 3. There are two major cities located in the area immediately bordering the bay. The larger of the two cities is Sandusky. It's 1970 census population was 41,175. Sandusky, besides being the larger of the two cities, exerts a larger influence on the environment of the bay. This greater influence may be attributable to its size or possibly its strategic position on the southeast side of Sandusky Bay. Fremont, the second major city, is situated upstream on the banks of the Sandusky River. Fremont's population as of the 1970 census was 18,490.

The total area of the Sandusky River watershed is 4596 square kilometers. Figure 4 illustrates the boundaries of the watershed, the counties contained within it, major towns and cities and major tributaries. The total population as of the 1966 census was 191,000.

The major land use in the counties bordering Sandusky Bay is projected to be 80% farmland by 1975, a 4% decrease from the 1958 statistics. Urban areas are projected to be using 17.5% by 1975 and by 1975. An increase of 5% over the 1958 figures. The remaining land is



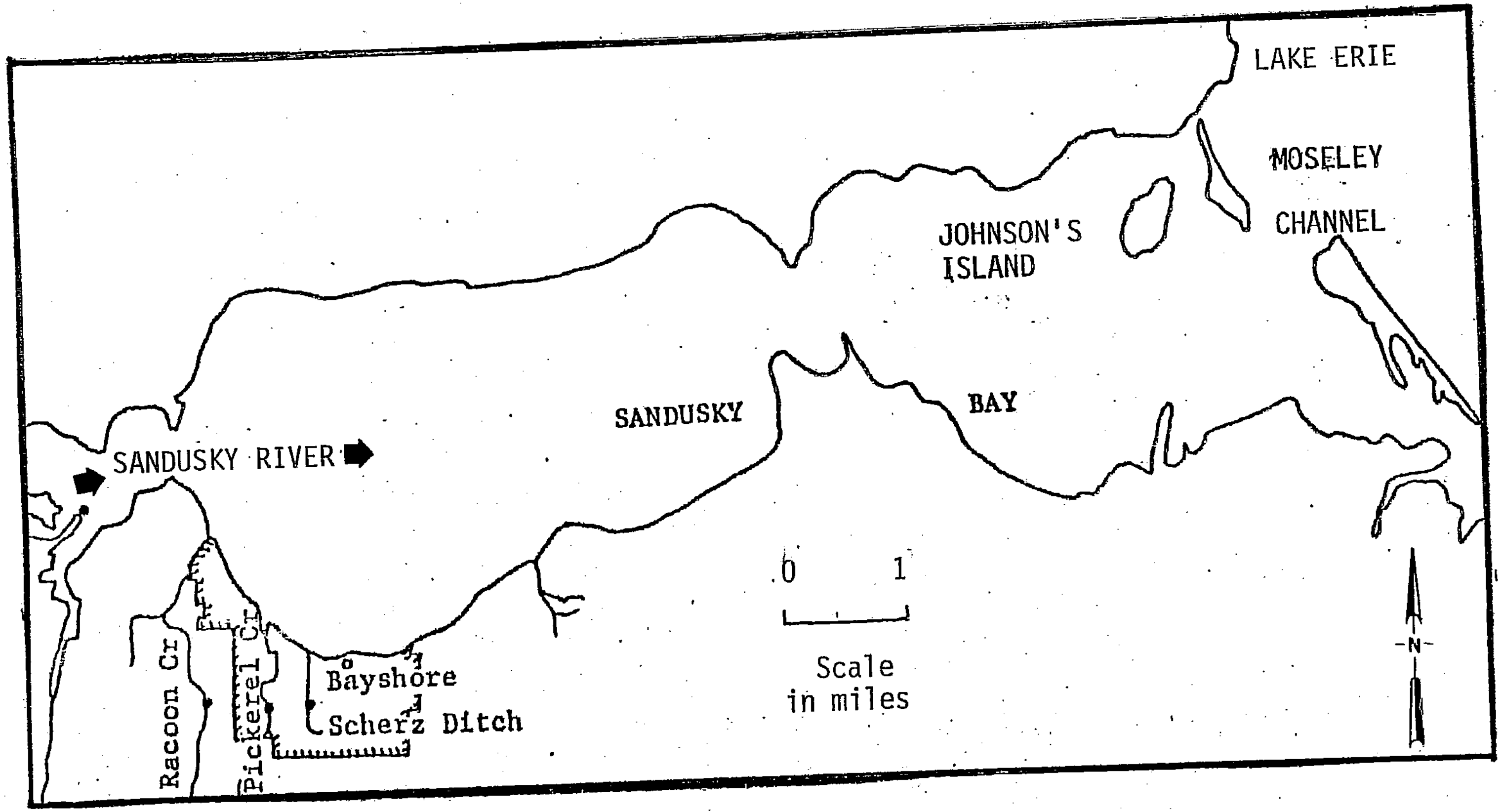


FIGURE 3. LOCATION OF SANDUSKY BAY AND PROPOSED POWER PLANT SITE

TABLE 3

COUNTIES IN THE SANDUSKY BAY WATERSHED

County	Population	County	Population
Crawford	50,364	Ottawa	37,099
Erie	75,909	Richland	129,997
Hardin	80,813	Sandusky	60,983
Huron	49,587	Seneca	60,696
Marion	64,724	Wyandot	22,415*

City Population

TABLE 4

COMMUNITIES IN THE SANDUSKY BAY WATERSHED

City	Population	City	Population
Attica	1,005	Helena	298
Bellevue	9,090	Morral	452
Bettsville	833	Nevada	991
Bloomville	884	New Rigel	340
Bucyrus	13,111	New Washington	1,251
Burgoon	221	North Robinson	277
Carey	3,948*	Republic	705
Catalia	1,045	Sandusky	32,674
Chatfield	291	Sycamore	991
Clyde	5,503	Tiffin	21,696
Crestline	6,378	Tiro	310
Fremont	18,490	Upper Sandusky	1,042
Green Springs	1,340		

Source: U.S. Census, 1968 (*) and 1970, as reported in the Ohio Almanac.

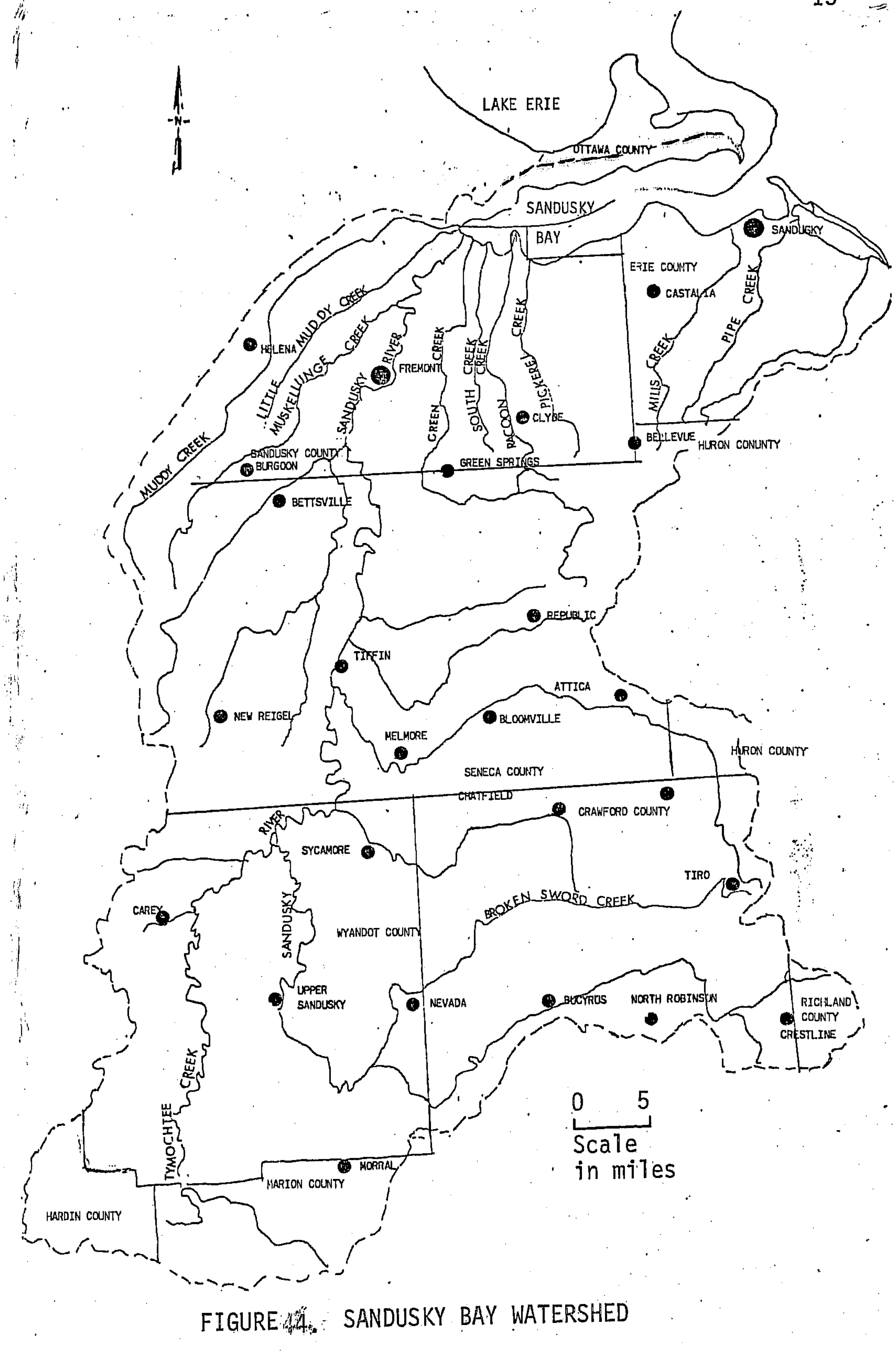


FIGURE 4. SANDUSKY BAY WATERSHED

Morphometry

A discussion of the morphometry of Sandusky Bay should be preceded by a general description of the classification of Sandusky Bay. Sandusky Bay is classified herein as an estuary of Lake Erie. Brant and Herdendorf (1972) presented data to indicate that Lake Erie has intruded upstream through Sandusky Bay to the Sandusky River to form an estuary. Brant and Herdendorf apply three basic concepts to all estuaries. These are a constriction at the entrance, continuous water exchange, and mixing of the two kinds of water. These processes are occurring in Sandusky Bay and influence the dynamics of the estuary.

The primary agents in determing the dynamics, according to Reid (1961), of an estuary are the morphological characteristics. The parameters of morphology as given by Reid (1961) are: maximum length, maximum breadth (or width), mean breadth (or width), maximum depth, mean depth, area, volume, length of shore, slope of basin and period of seiche. These parameters are listed for Sandusky Bay in Table 5. The formulas by which these values were derived are from Reid (1961) and are given in Table 6.

The maximum length as defined in Table 6 is the shortest distance between the farthest over water points on shore. This length is the distance available for water level fluctuations. These changes in water level may be long term or short term and are dependent on depth and slope of the basin as well as basin length. The long term fluctuations may occur with changes in precipitation, seasons or occur over a number of years. Short term fluctuations are due to the tilting of the lake

TABLE 5
MORPHOMETRY OF SANDUSKY BAY

Measurement	Western Basin	Eastern Basin	Total
Maximum Length	12.41 km	12.98 km	23.93 km
Maximum Width	7.44 km	7.63 km	7.63 km
Mean Width	5.90 km	4.47 km	5.58 km
Maximum Depth	2.75 m	3.96 m	3.96 m
Mean Depth	1.20 m	1.55 m	1.61 m
Area			
Total	74.41 km^2	58.87 km^2	162.48 km^2
0- .6 m	8.22 km^2	5.43 km^2	13.65 km^2
.6 -1.2 m	22.12 km^2	11.86 km^2	33.98 km^2
1.2 -1.8 m	42.68 km^2	24.37 km^2	67.05 km^2
1.8 -2.4 m	0.97 km^2	12.11 km^2	13.08 km^2
2.4 -4.0 m	0.16 km^2	5.10 km^2	5.26 km^2
Seiche, Period	2.02 hrs	1.85 hrs	
Length, Shoreline	36.15 km	37.27 km	73.42 km
Slope of Basin	.09	.19	
Volume, Total	.089 km^3	.091 km^3	.180 km^3

*Longitudinal seiche

TABLE 6. FORMULAS FOR MORPHOMETRY PARAMETERS

Parameter	Formula
Maximum Length	Shortest distance between the farthest over-water points on the shore. (l_m)
Maximum width	The distance from shore to shore measured at right angles to the maximum length. (w_m)
Mean Width	$\bar{w} = \frac{A}{l_m}$
Maximum Depth	Deepest point in the basin. (d_m)
Mean Depth	$\bar{d} = \frac{V}{A}$
Area	The number of planimeter units in the basin divided by the number of planimeter units per kilometer squared.
Volume	$V_I = 1/3\ (A_1 + A_2 + \sqrt{A_1 A_2})h$ $V = \sum V_0 + V_1 + \ldots\ldots + V_{n-1}$
Seiche, Period (Longitudinal)	$t = 2l_m \sqrt{dg}$ g=gravity acceleration
Length, Shoreline	Chartometer units per distance measured divided by chartometer units per mile.
Slope of Basin	$\bar{S} = \frac{1}{2}(\frac{1}{2}l_0 + l_1 + \ldots\ldots\ldots l_{n-1} + \frac{1}{2}l_n)\frac{d_m}{A}$ l_0, l_1, ...are contours.

surface by wind or atmospheric pressure differentials. In Sandusky Bay wind is probably the more important force. In order for pressure differentials to cause changes in the water level there must be a distance between the two pressure levels through which the change can occur. Sandusky Bay has a maximum length of only 24 kilometers.

Sandusky Bay water levels are also influenced by Lake Erie water levels and activity. Since the bay is an estuary where continuous mixing and exchange of lake and bay water is occurring, changes in the lake level are conveyed to Sandusky Bay. Lloyd (1974) found that the long term variations in Sandusky Bay water level were following two simultaneous cycles. The first cycle was the seasonal variation of the Great Lakes Basin. The second cycle, related to precipitation and evaporation, over a number of years and results in maximum and minimum bay levels. Presently Lake Erie and Sandusky Bay are under going a period of maximum water level.

On a short term basis the bay is influenced by Lake Erie wind tides and seiche activity as well as its own wind tides and seiche activity. Wind tide is defined as the banking up of water on the windward shore. A seiche occurs when the pressure causing the water to bank is released and the lake surface oscillates freely (Herdendorf and Braidech, 1972).

The effects of these water level fluctuations on a basin as shallow as as Sandusky Bay (mean depth 1.61 m) can be quite important. The beds of South Creek, Muddy Creek and Muddy Creek Bay would be exposed at their lower reaches by a .61 m decrease in the water level. The nearshore bottom of the bay, especially in the western basin would be exposed for a distance. An increase in water level would flood the surrounding march marshes and farm land. A long term change in the water level due to the previously discussed cycles could cause a permanent change in the ecosystem by eliminating one type of habitat and replacing it with a second habitat type. A short term fluctuation (wind tide or seiche) could result result in the elimination of a portion of the community in the area affected by the fluctuation. Thus eggs spawned in shallow water, plan plankton, benthos and fish populations could be reduced in those areas. A short term fluctuation would expose the area for about two hours. This is the period of the seiche, or the time it takes the energy transfer to travel from one end of the bay to the other.

The length of the shoreline indicates the irregularity of the basin. and is often used as a measure of productivity. Another indication of productivity is the amount of shallow flowage. The more shallow flowage the greater the plankton populations are likely to be (if turbidity is not high).

The slope of the basin has been mentioned as an important factor in determining seiche activity. It is also an important factor affecting benthic populations.

Geology

The area surrounding Sandusky Bay has probably been glaciated four times. The present surficial till is thought to be from the Wisconsin Ice Sheet (White, 1943). The glacial erosion that occurred with the advance and retreat of the ice sheets occurred parallel to the axis of Lake Erie and Sandusky Bay. The glacial grooves found in the area indicate a paral- le parallel movement. After the Wisconsin ice sheet retreated, lacustrine deposits were laid down by the glacial lakes of the Pleistocene (Moseley, 1904). The glacial lakes that covered Sandusky Bay were: Maumee, Arkona, Whittlesey, Wayne, Warren, and Elkton (Leverett and Taylor, 1915).

Sandusky Bay presently occupies the lower reaches of the Sandusky River Valley. The bay was formed following a regional uplift at the Niagara outlet 4,000 years ago. Waters which formerly flowed eastward from the upper Great Lakes by way of the Ottawa River moved southward into the Lake Erie Basin. With this increase in drainage area, the water level of Lake Erie rose from approximately 560 to 573 feet above mean sea level. This higher lake level caused the lower Sandusky River Valley to flood producing the present bay (Leverett, 1931). Marshes formed along both banks and waves began to erode the non-resistant glacial till. The bay is continuing to increase its area due to the tilting of the Great Lakes and the continued erosion of the banks.

Bedrock in the Sandusky Bay area is of the Monroe Group, Bass Island and Detroit River Formations. The Bass Island Formation is placed in the Devonian. The actual rock types are shown in Figure 5. The rock types are Bass Island Formation: Tymochtee Shaly Dolomite, Rasin River and Put-in-Bay Dolomites; Detroit River Formation: Amherstburg and Lucas Dolomite (Carman, 1927). The bedrock outcrops occur in areas where wave action has removed the overlying unconsolidated materials (Pincus et al. 1951). Chemically, limestone is a rock composed essentially of calcium carbonate with minor quantities of other basic carbonates,

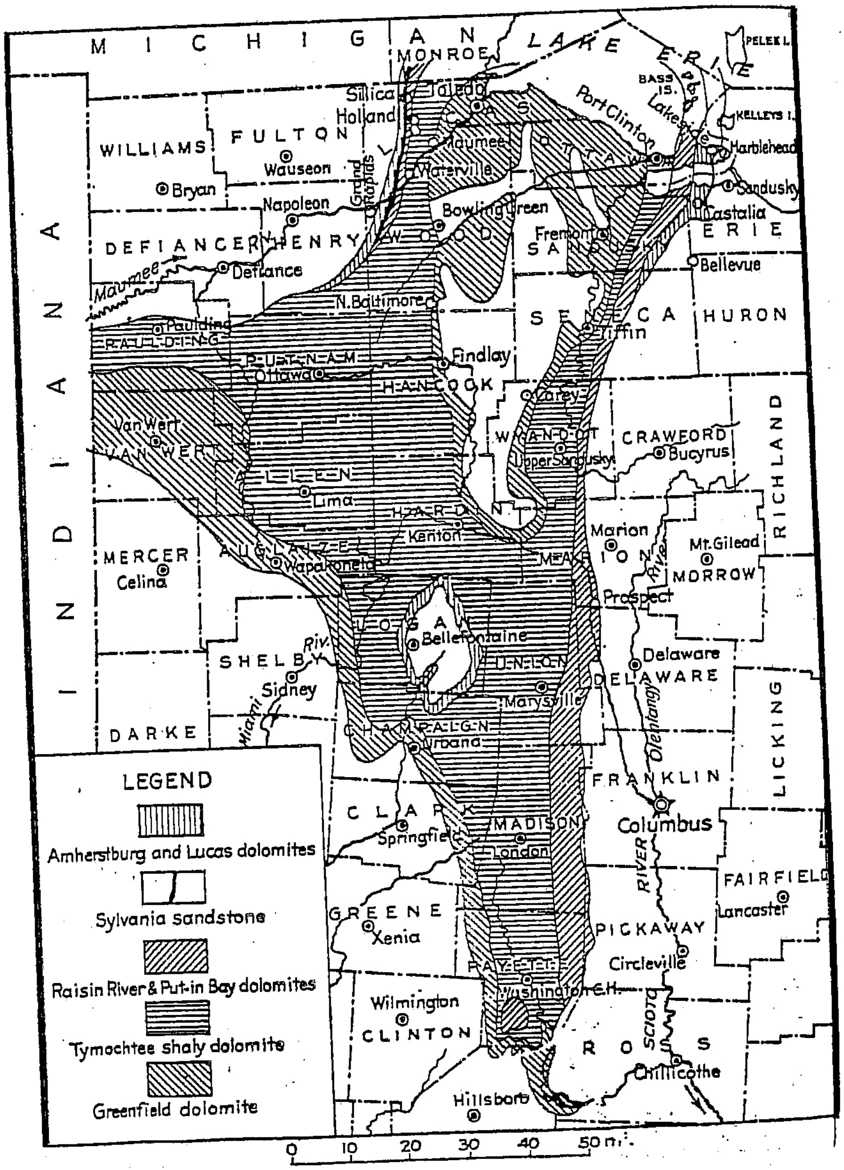


FIGURE 5. BEDROCK GEOLOGY IN THE SANDUSKY BAY BASIN
(Carman, 1927)

sulfates, sulfides, phosphates and silicates. Generally they contain from 80-98% calcium carbonate. Dolomite is composed largely of magnesium carbonate combined directly with calcium carbonate in the molecular ration of one to one. Theoretically dolomite is 45.73% magnesium carbonate and 54.27% calcium carbonate (Stout, 1941).

Sediments

Herdendorf (1964) found the bottom deposits west of Johnson Island to be mud (semi-fluid silt and clay sized particles) sand, gravel and bedrock. This soft lake mud (originally suspended in the water) forms a sediment formed 1-2 meters thick. The average particle size is clay (60%), silt (38%) and sand (2%) (Ohio Department of Natural Resources, 1953). Sand does occur, however, around Sand Point and north of Johnson's Island. In the area north of the island the sand is mixed with clay and mud. Beneath the mud is a very compact clay (Forsyth, 1972).

A core from the eastern basin of Sandusky Bay was analyzed for mercury content. The surface value was 0.34 ppm dry mercury (Walters, et al., 1974). The mercury values at various depths are given below:

0-2 cm	0.34 ppm dry mercury
5-6	0.44
10-11	0.39
19-20	0.31
34-35	0.12

The half-depth value for Sandusky Bay was relatively high, 25 cm. The half-depth is the depth at which the value of mercury has been reduced to half of the surface value. This could indicate a steady but low level of mercury input to the system. The value could also be an aberration caused by currents and resuspension. A natural background level for mercury is 0.002-0.07 ppm. Mercury enters the system from the atmos- sphere, tributaries, shore erosion, municipal and industrial outfalls. Microorganisms in the surface sediment convert solute mercury into methyl mercury compounds which enter the food chain and are accumulated in fish and other aquatic organisms. Ther mercury in oligochaetes and chironomids samples was less than 0.1 ppm.

Soils

The four major soil types of northwestern Ohio all occur in the dr drainage basin of Sandusky Bay. The major soil types are: 1) soils of the lake bed of glacial Lake Maumee; 2) relatively high-lime soils form- formed from Wisconsin glacial age till; 3) soils of the old lake bed region; and 4) relatively low-lime soils formed from Wisconsin glacial till. Type 1 and 2 soil groups compose the bulk of the Sandusky Bay drainage area soils. Soil type 3 is present in the northeastern ex- tremity. Soil type 4 is found in the southeastern area of the basin (Ohio Department of Natural Resources, 1967). The topography of this area is quite flat, having a slope of 8-10 feet per mile (U.S. Army Corps of Engineers, 1953).

Shore Materials and Geological Processes

In the area of Sandusky Bay, bedrock is covered by a 40-foot layer of glacial till and a 20-foot layer of lacustrine clay to give a total of 60 feet of surficial material. The till is compact and calcareous composed dominantly of clay and silt with a small amount of sand and pebble sized material, and rare boulders. The till is saturated with as much water as its compact nature will allow. The water is held tightly and cannot be tapped or drained. Between the till and bedrock is a sporadic thin zone (about five feet) of a combination of broken fragments of bedrock, meltwater-washed sediments, and/or other periglacial type materials, permeable in some places, impermeable in others. The till is highly erodable, being composed of mainly silt and clay (mostly clay) (Forsyth, 1972).

The waters of the Sandusky River flow slowly to the lake. There are no strong currents to contribute to the geological process of shore erosion (Moseley, 1904). The major factors in shore erosion in Sandusky Bay are high winds and high lake levels. Because of the shallow nature of the bay waves seldom are higher than 30 inches. This low wave action on the non-resistant bluffs is sufficient to cause a severe erosion problem. The average erosion rate is 5-8 feet a year (average of 125 years; 1820-1945; U. S. Army Corps of Engineers, 1953). The bedrock outcrops are highly resistant but occur in few places (Humphris, 1953). During cycles of high water (seasonal or long term) more rapid erosion occurs. Short term increases caused by high winds create a double erosion problem by increasing the water level and setting up wave action (Shaffer, 1951). The Ohio Department of Natural Resources in a 1961 estimate of erosion stated that in the unprotected stretches nearly all of the Sandusky Bay shore shows rapid retreat losing as much as 10-15 feet per year. Protected areas show little retreat.

The Sandusky Bay area is thought to be subsiding. The movement is usually ascribed to isostatic recovery of elevation following depression of the earth's crust due to the weight of the ice. This subsidence is causing the south shore of Lake Erie as well as Sandusky Bay to become lower with respect to the outlet of Lake Erie at Buffalo. The rate of relative subsidence of the earth's surface and corresponding increased depth of water at Sandusky Bay amounts to about 0.5 foot per 100 years (U. S. Army Corps of Engineers, 1953).

Seismicity of the Sandusky Bay Area

The seismic risk map developed by ESSA/Coast and Geodetic Survey (1969) divides the United States into four major zones of earthquake damage. Zone 0, no damage; zone 1, minor damage; zone 2, moderate damage age; and zone 3, major damage. The Sandusky Bay area is in zone 1 with zone 2 impinging slightly on the west. A further breakdown of actual sites of occurrence indicated only two sites of seismic activity in the drainage basin of Sandusky Bay. The first reported earthquake occurred on July 11, 1930, intensity IV. The second earthquake occurred February 2, 1975, intensity I (Columbus Dispatch, February 3, 1975)). Two earthquakes over a 200 hundred year history indicates that this section of Ohio, like the rest of the state is not seismically active.

Climatology

Northwest Ohio is located in the north temperate zone. The climate is humid, the summers warm and the winters mildly cold. The average temperature is 51°F. The average monthly maximum is 75°F; the average monthly minimum is 27°F, The frost free season averages 170 days (Ohio Department of Natural Resources, 1967).

The average percipitation for the Sandusky Bay drainage basin is 32-36 inches of rain per year; annual evaporation is 33 inches per year (Ohio Deaprtment of Natural Resources, 1967).

Average wind speed at Sandusky, Ohio is 9.6 mph, from the southwest (Figure 6). The strongest winds are also generally from the southwest (Figure 7). The average monthly velocity in miles per hour 1948-1957 for eight directions is given in Table 7 (Verber, 1959). Maximum wind velocities indicate that the southwest winds are of much greater force than any of the others and of a greater frequency. The highest monthly average winds occur in the winter, however, the record breaking winds are likely to appear in the spring. Spring is also the season of maximum tornado occurrence in Ohio.

The average solar radiation reading is 393 langleys/day. A maximum of 634 langleys/day was recorded in September, 1973. A minimum of 195 langleys/day was recorded in April, 1974 (Battelle, 1974).

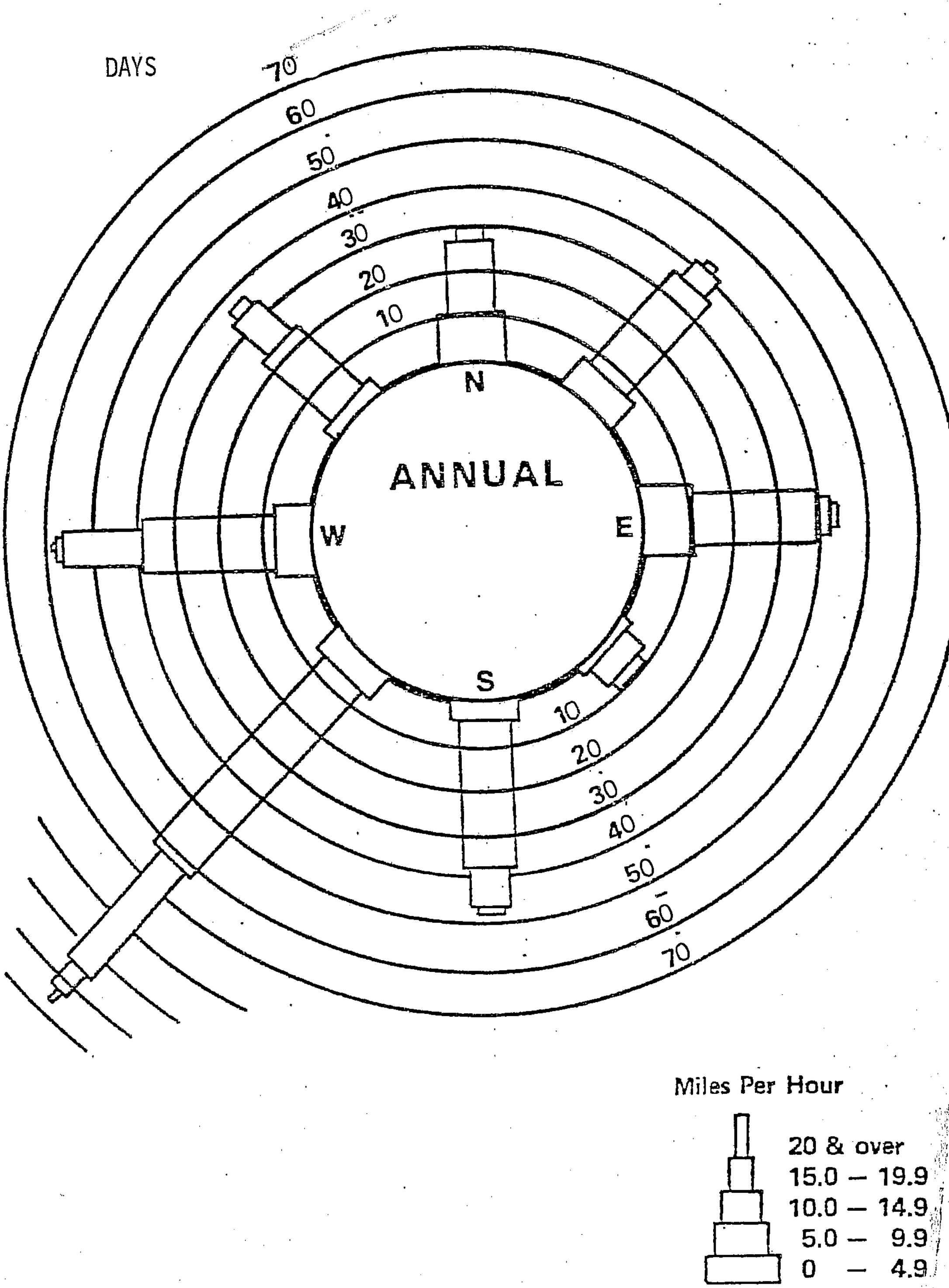
Hydrology

Tributaries. The Sandusky Bay drainage basin covers 4,591 square kilometers. The Sandusky River is the largest tributary in the basin draining 3,680 square kilometers. The remaining 911 square kilometers are drained by a number of small streams. Table 8 lists the streams according to the western and eastern basins. The drainage area of each stream is given. The western basin drains 94% of the total watershed while the eastern basin drains the remaining 6%. Other sources of input are direct precipitation, surface runoff, and groundwater.

TABLE 7. AVERAGE MONTHLY WIND VELOCITY IN MILES PER HOUR 1948-1957

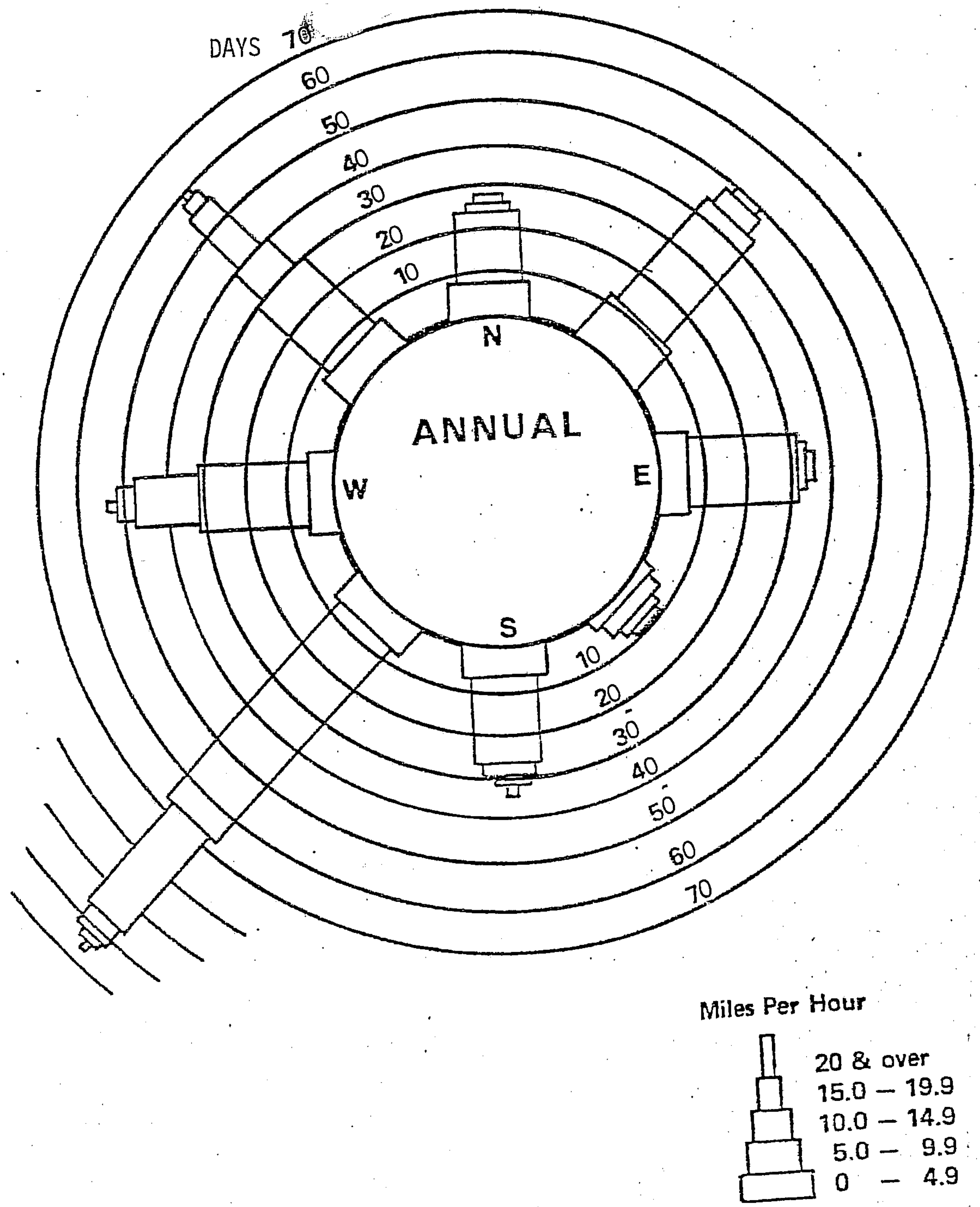
(Verber, 1959)

	N	NE	E	SE	S	SW	W	NW	Combined
Jan	7.4	9.1	9.1	8.5	9.9	10.4	9.6	9.5	9.6
Feb	7.2	9.1	7.1	8.1	8.8	10.5	10.0	6.0	8.9
Mar	7.7	9.4	8.8	7.1	10.2	11.5	11.1	10.1	10.9
Apr	6.8	7.9	7.9	6.5	7.9	10.6	9.5	10.4	9.0
May	6.3	7.5	6.6	6.3	7.6	9.0	8.4	8.9	7.8
June	5.0	5.8	5.8	6.0	7.0	8.4	6.8	7.0	6.8
July	5.0	6.0	5.6	5.7	6.6	6.2	8.1	7.1	6.5
Aug	5.3	6.6	5.3	5.1	5.9	6.4	6.1	7.0	6.1
Sept	5.0	7.0	6.0	5.6	6.1	7.6	7.5	7.7	6.9
Oct	7.2	7.3	5.6	7.0	6.5	8.4	8.5	9.2	7.6
Nov	6.8	8.8	8.0	8.6	8.5	10.1	10.7	10.1	9.6
Dec	8.1	9.5	7.3	11.9	9.2	10.3	9.4	9.1	9.6



Period 1948-1957, Sandusky Ohio

FIGURE 6. ANNUAL AVERAGE WIND FREQUENCIES AT SANDUSKY, OHIO (Verber, 1959)



Period 198-1957, Sandusky, Ohio

FIGURE 7. ANNUAL MAXIMUM WIND FREQUENCIES AT SANDUSKY, OHIO (Verber, 1959)

TABLE 8

DRAINAGE AREAS OF STREAMS TRIBUTARY TO SANDUSKY BAY

Tributary	Area (sq. km.)
Western Basin	4314
Sandusky River (includes Yellow Shale and Green Creeks)	3680
South Creek	57
Muddy Creek (includes Little Muddy Creek)	287
Raccoon Creek	88
Pickerel Creek	119
Stream thru York	
Stream thru White's Landing	83[1]
Little Pickerel Creek	
Eastern Basin	277
Cold Creek	23
Mills Creek	109
Pipe Creek	75
Plumbrook Creek	18
Marblehead Peninsula Drainage	52[2]
Total	4591

(Ohio Department of Natural Resources, 1967; Battelle, 1974)

[1]Estimated value for all three streams.

[2]Estimated value.

Groundwater. The quality of groundwater in the study area has been rated as "fair" by the Ohio Division of Water. The rating is based on the most unsatisfactory chemical property. The chemical analysis measured hardness (as calcium carbonate), dissolved solids, fluoride, chloride, sulfate and iron. In the study area hardness and dissolved solids are the two major parameters with high values. Table 9 gives the mean value and the range for all stations in the watershed and the water quality criteria used by the Ohio Division of Water in the rating (Ohio Department of Natural Resources, 1966).

TABLE 9.
SANDUSKY BAY GROUNDWATER QUALITY (PPM)

Parameter	$CaCO_3$	Dissolved Solids	F	Cl	SO_4	Fe
Mean	731	1011	1.29	17.9	572	2.9
Range	334-1810	371-2740	.3-2.1	0-107	3.0-2321	.02-30
Excellent	< 120	< 500	< 1.5	< 250	< 250	< .3
Good	< 200	< 1000	< 1.5	< 500	< 500	< 1.0
Fair	> 200	> 1000	> 1.5	> 500	> 500	> 1.0

All values are in ppm. $CaCO_3$, calcium carbonate; DS, dissolved solids; F, Flouride; Cl, chloride; SO_4, sulfate; Fe, iron.

Table 9 shows iron and sulfate in high concentrations and chloride and fluoride as being present in low concentrations (excellent rating).

The groundwater in the Sandusky Bay drainage basin flows north-northwest toward the bay. As the water moves through the bedrock it acquires carbonates from the limestone and dolomite; and sulfates from the gypsum deposits (Ohio Department of Natural Resources, 1967).

groundwater table near the bay is close to the surface as indicated by the presence of several artesian wells along the western basin's south shore.

Thermal Structure. Ice data collected in 1966 by the Ohio Geological Survey (Liebenthal, 1966), and in 1974 by Battelle Memorial Institute indicate that Sandusky Bay is in a continual state of flux. Water movement is actively occurring throughout the winter resulting in a continual cycle of freezing and thawing. The 1966 data shows the bay frozen from January through the middle of February with no open water. Thawing and refreezing were evident by the cracks which were noted in both January and February. The 1973-74 data gave two periods of entire ice cover separated by an ice free period. The ice cover periods were from mid-December through the 24th of January and the 14th of February through the 27th of February. Open water existed from January 26, 1974 through February 3, 1974.

Suspended Materials. Turbidity is a measure of the suspended materials in the water column. As the amount of suspended material increases the turbidity increases. Since the suspended materials scatter and absorb light there is less light penetration. The actual depth of light penetration was measured in Sandusky Bay with a secchi disc and referred to as transparency. Figure 8 shows transparency and turbidity on the same axis plotted against time. It can be seen from Figure 8 that as turbidity increases transparency decreases making the two graphs like mirror images. Statements concerning the variability of the actual values are difficult to make. Sandusky Bay is very shallow and

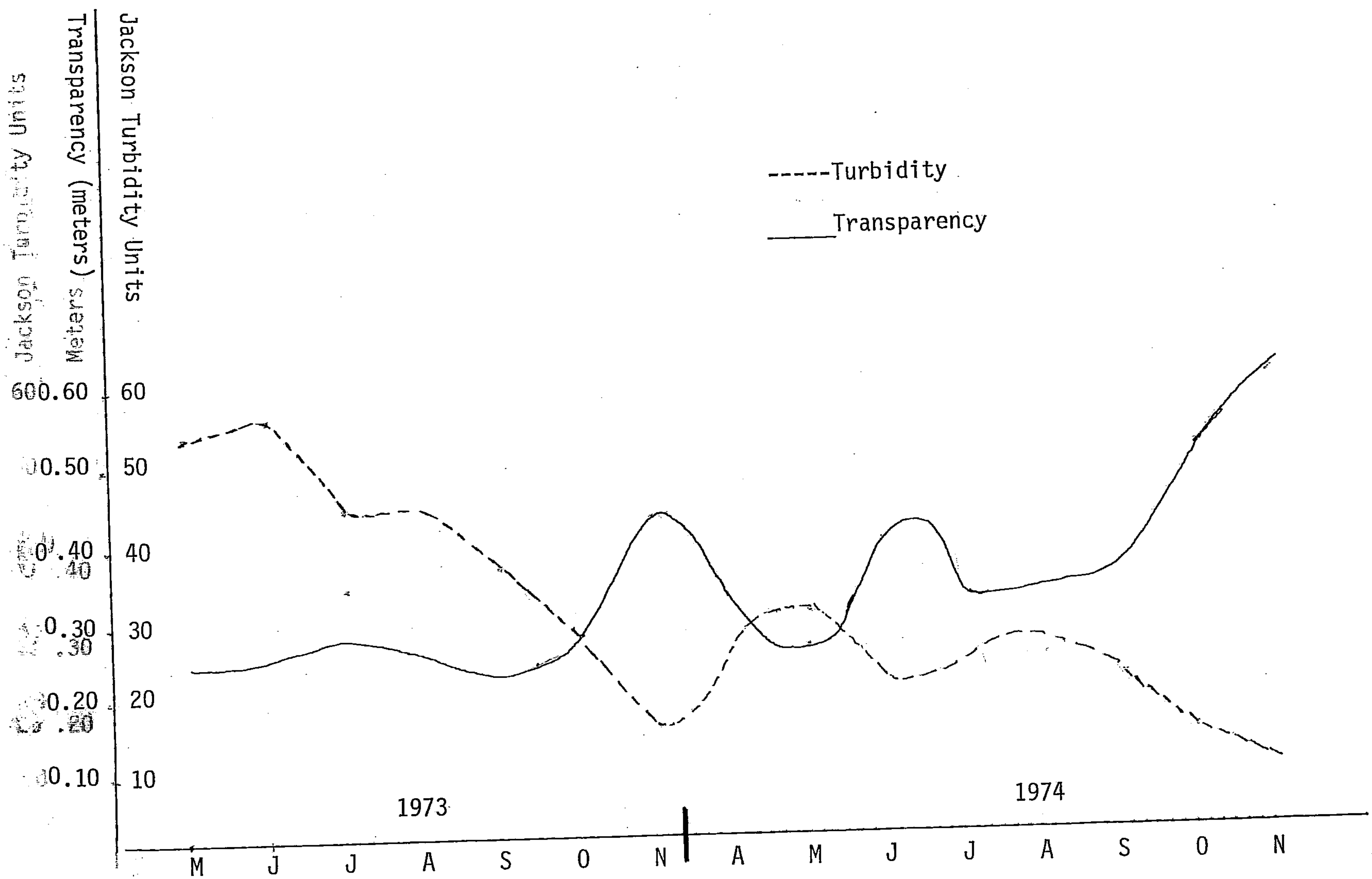


FIGURE 8. TRANSPARENCY AND TURBIDITY PLOTTED AGAINST TIME

highly susceptible to rapid changes initiated by wind. The central area of the bay bottom contains a thick mud sediment which is easily suspended in in the water column. Near shore areas are more drastically affected by stream flow and runoff. However, there appears to be an increase in turbidity in the spring and a decrease in the winter.

Photosynthesis is limited to areas of adequate light penetration. Thus photosynthesis is limited by the turbidity-transparency realtionship. Temperature is also very important in photosynthesis and may, in part, offset low transparency values for Sandusky Bay.

Vertical Movements. Vertical movements in Sandusky Bay are divided into long term and short term variations. Long term changes in the water level of Sandusky Bay are equal to those of Lake Erie. The small opening between Sandusky Bay and Lake Erie (Moseley Channel) makes the bay slower to respond to short term changes in lake level. Secondary features of the slow initial response of the bay to short term lake level changes are that the bay does not reach the extremes of the lake and requires longer to return to mormal level.

Since bay levels are assumed to vary directly with Lake Erie levels, it is necessary to discuss the plane of reference used on Lake Erie. The International Great Lakes Datum (IGLD, 1955) is defined as mean water level in the Gulf of Saint Lawrence at Father Point, Quebec. Low Water Datum (LWD) for Lake Erie is established at an elevation of 5.68.6 feet above IGLD.

Long term changes in the water level of Sandusky Bay are caused principally by: precipitation, evaporation, runoff, and crustal movement (Verber, 1959). Two long term cycles are evident in Sandusky Bay. The first cycle is a seasonal cycle, reaching its peak during June-August and its low during January-February (Battelle, 1974). The seasonal cycle is controlled primarily by evaporation, precipitation, and run-off. A second cycle has been postulated, of a 10-15 year duration. This cycle occurs simultaneously with the seasonal cycle (Lloyd, 1974).

Lake Erie and Sandusky Bay are presently at a "peak" level (573.5 LWD), the highest recorded level in 114 years. The lowest level on record is 567.5 (LWD) recorded in February, 1937. Sandusky Bay has varied six feet in its recorded history. In

Short term water level changes are caused by wind setup resulting in free oscillation or tilting of the water surface (seiches). Seiches on Lake Erie are responsible for the extreme recorded instantaneous water levels of Sandusky Bay. The maximum instantaneous level was six feet above Low Water Datum at Sandusky during the 1972 storm (Herdendorf, 1973). The extreme instantaneous minimum occurred in January, 1942, recorded at 5 feet below Low Water Datum. Figure 9 gives the frequency of various seiche amplitudes at the mouth of Sandusky Bay. The greatest seiche amplitude indicated for Sandusky Bay is less than 2.5 feet with an average recurrence period of 100 months. However, 2.0 foot seiches occur with an average recurrence period of less than 12 months.

Seiche activity in Sandusky Bay is often initiated by Lake Erie but is not limited to that source. Wind-setups occur in both the western and eastern basins operating separately. Figure 10 shows the effect of a seiche on the water levels in Lake Erie, and both basins of Sandusky Bay. The

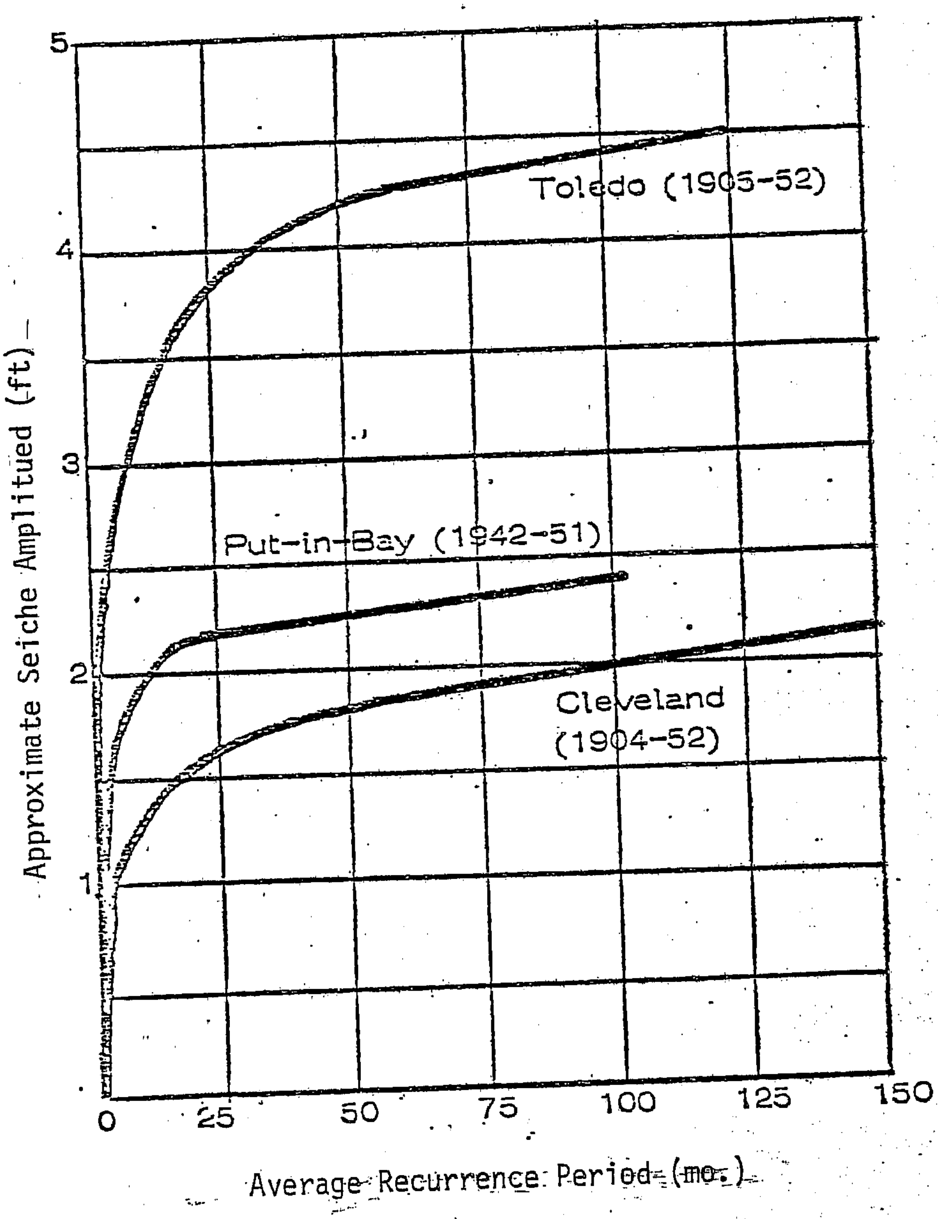


FIGURE 9. Frequency of various seiche amplitudes at the mouth of Sandusky Bay (based on records at Put-in-Bay). Records at Toledo and Cleveland included for comparison. (Derived from R. Sykes, Ohio State University, CLEAR, Progress Report to American Electric Power Corporation, 1973).

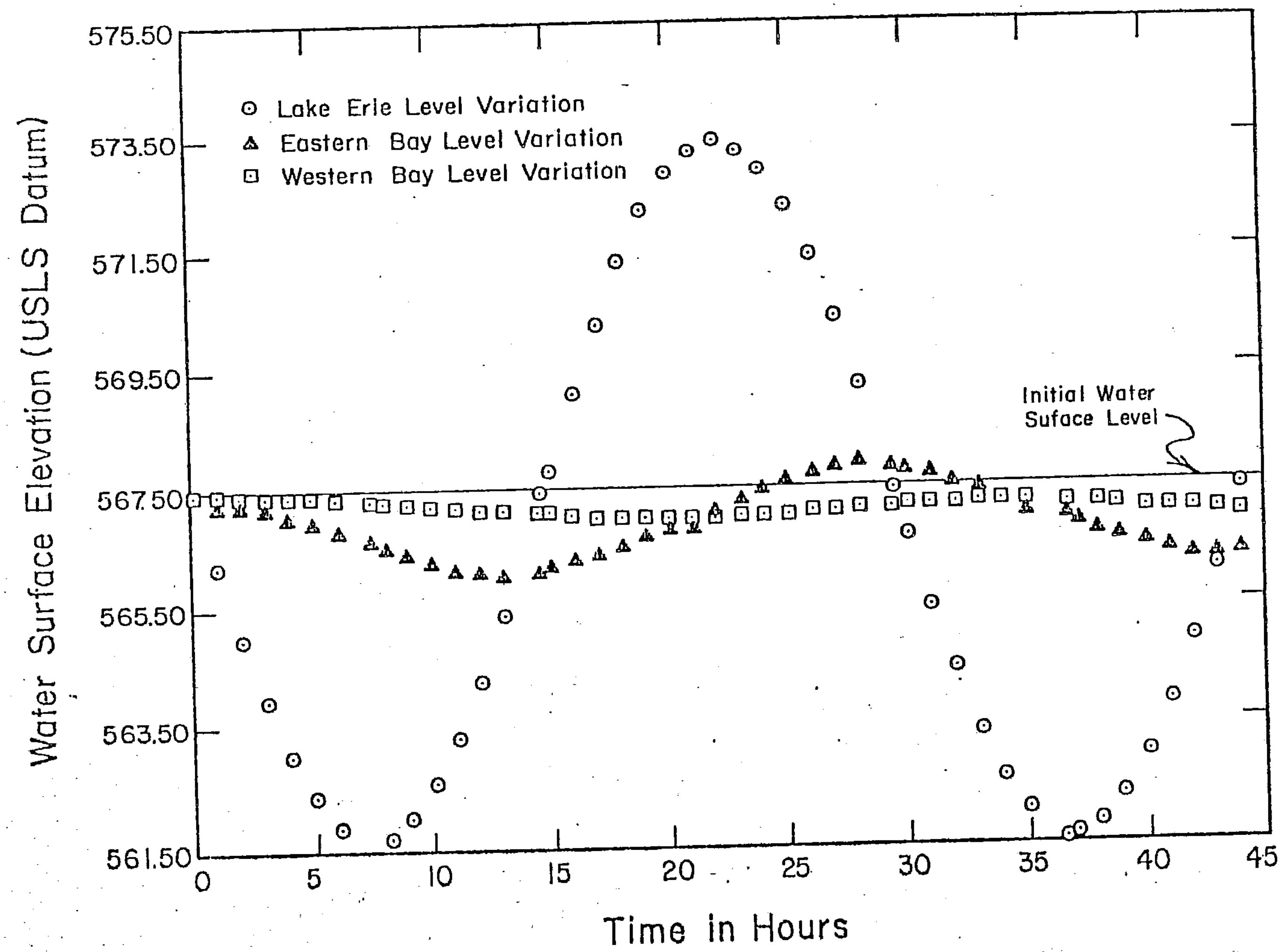


FIGURE 10. LAKE ERIE, EASTERN AND WESTERN SANDUSKY BAY BEHAVIOR DURING SEICHE ACTIVITY (Lloyd, 1974)

amplitude of the seiche is greatly reduced in the eastern basin and the western basin is oscillating half as much as the eastern basin. Moseley Channel and the restriction at the bridges reduce the rate and force of the incoming seiche.

<u>Horizontal Movement</u>. Currents in Sandusky Bay vary depending on location of observation, wind direction, and wind speed. Ohio Geological Survey in the summer of 1971 and fall of 1972 found rapid currents near the bridge openings. In the remaining area of the bay currents were dependent on wind speed and direction for their motivation. A 1961 study by Ohio Geological Survey (1966) measured the average velocity at the surface and at five-foot and ten-foot depths. The average surface current was 0.66 ft/sec., at five feet, 0.44 ft/sec. and at 10 feet, 0.39 ft/sec. Measurements made at the mouth of Sandusky Bay indicated an a average current of 1.25 ft/sec. Measurements taken during the present study from September, 1973 to April, 1974 indicated average nearshore currents of only 0.09 ft/sec. Nearshore currents were greatest during November, March and April.

Moseley (1903) summed up Sandusky Bay currents. According to Moseley, currents in the bay are dependent on three factors: 1) position of measurement with reference to shores or shoals; 2) direct action of the wind; and 3) entrance of bay-water entering or leaving. The importance of these three factors is supported by the measurements previously discussed. Nearshore currents are considerably less than offshore currents, while offshore currents are greatest at the surface decreasing with depth. Wind action was indicated by Ohio Geological Survey as being the dominant factor in current speed and direction. It is interesting to note that the months with the greatest average current speeds (November, March and April) also had the highest waves (.68, .98 and .86 feet). Since shear stress between the wind and water sets the upper layers of water in motion, causing waves, and the waves and currents increase and decrease together, there is further evidence of the relationship of wind to current direction and speed.

The overall average wave height for the months measured (September, 1973-April, 1974) was 0.49 feet with a range of 0-3.00 feet.

CHEMICAL LIMNOLOGY

Water Quality

Water quality parameters measured regularly throughout the study were were: temperature, conductivity, dissolved oxygen, alkalinity, pH, and silica. Measurements for nitrate nitrogen and orthophosphate were made in 1973. Parameters were measured at surface and bottom at stations 5, 17, 21, 29, 33, 35,36,37,38.

Values for each parameter were grouped according to month and station. The mean, maximum, minimum and range were obtained using the IRCC computer and program BMDO1D. The Z statistic was calculated for comparisons of surface to bottom values at each station, station to station and month to sucessive month. The Z statistic is defined as:

$$Z = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{SE_1^2 + SE_2^2}}$$

$\overline{X}$=mean value
SSE=standard error

The 95% confidence level was used in determining significant differences.

Temperature. A comparison of surface to bottom values for temperature at all stations showed no significant differences. A comparison of all stations to each other revealed no significant differences between stations throughout the bay. Table 10 lists the mean, maximum, minimum, and range for each station. The data were regrouped and analyzed by months As expected every month was significantly different from the month previous and following. The mean, maximum, minimum and range for each month is given in Table 10. Temperature ranged from a monthly mean of 4.35 C

42

TABLE 10. SANDUSKY BAY TEMPERATURES (°C)

SANDUSKY BAY MONTHLY TEMPERATURE
November 1972-November 1974

Month		Mean	Maximum	Minimum	Range
Nov.	S	8.7	8.9	8.1	.8
1972	B	8.6	8.9	7.8	1.1
March	S	6.2	8.4	5.3	3.1
1973	B	5.9	6.7	4.7	2.0
May	S	15.7	16.4	15.0	1.4
1973	B	15.4	15.6	15.0	.6
June	S	23.7	27.2	22.2	5.0
1973	B	23.5	26.7	21.1	5.6
July	S	27.0	28.9	24.5	4.4
1973	B	26.0	27.8	24.0	3.8
Aug.	S	25.7	27.0	23.0	4.0
1973	B	24.6	26.0	23.0	3.0
Sept.	S	20.9	23.5	19.0	4.5
1973	B	20.8	23.5	19.0	4.5
Oct.	S	16.3	20.0	12.0	8.0
1973	B	16.1	20.0	12.0	8.0
Nov.	S	6.9	10.0	5.0	5.0
1973	B	6.8	10.0	5.0	5.0
April	S	16.0	17.7	12.9	4.8
1974	B	15.8	17.4	12.8	4.6
May	S	18.6	19.7	17.5	2.2
1974	B	18.2	19.7	16.8	2.9
June	S	21.0	21.9	19.7	2.2
1974	B	20.6	21.9	19.4	2.5
July	S	22.6	23.3	22.0	1.3
1974	B	22.2	23.0	22.0	1.0
Aug.	S	24.7	26.0	24.0	2.0
1974	B	24.4	25.5	24.0	1.5
Sept.	S	15.3	17.0	14.0	3.0
1974	B	14.9	16.0	14.0	2.0
Oct.	S	9.6	10.5	9.0	1.5
1974	B	9.4	10.5	9.0	1.5
Nov.	S	4.3	5.0	3.0	2.0
1974	B	4.1	5.0	3.0	2.0

SANDUSKY BAY STATION TEMPERATURES
November 1972-November 1974

Station		Mean	Maximum	Minimum	Range
5	S	20.6	27.0	6.0	21.0
	B	19.7	26.0	6.0	20.0
17	S	19.5	28.4	5.0	23.4
	B	18.9	28.1	5.0	21.1
21	S	18.8	27.5	6.0	21.5
	B	18.7	26.7	6.0	21.7
29	S	20.1	27.2	5.0	22.2
	B	19.8	27.0	5.0	22.0
33	S	20.2	26.5	9.0	17.5
	B	19.8	25.9	9.0	16.9
35	S	20.4	26.7	9.0	17.7
	B	20.2	26.1	8.5	17.6
36	S	19.8	25.0	10.0	15.0
	B	19.6	25.0	9.0	16.0
37	S	19.9	25.0	10.0	15.0
	B	19.5	25.0	10.0	15.0
38	S	19.3	27.2	8.5	18.7
	B	19.1	25.6	9.5	16.1

are given in Table 10. Temperature ranged from a monthly mean of 4.3°C (November, 1974) to a high of 27.0°C (July, 1973).

<u>Conductivity</u>. Surface to bottom comparisons at all stations showed no significant differences. Significant differences in conductivity were found between stations 36, 38 and all other stations (Table 11). Stations 36 and 38 are the two stations located closest to the mouth of the bay. At this point lake and bay water mix, lowering the conductivity at these stations. Herdendorf (1965) reported the mixing of lake water with the bay water resulting in a plume of lower conductivity water extending into the bay. The mean value for station 38, closest to the lake was 350 micromhos/cm. The mean value for station 36 was 400 micromhos/cm.

Month to month variations took place during 1973 and 1974 (Table 11). In 1973, March to July and August to September were significant. In 1974, May to June and June to July were significantly different. May to June values decreased while June to July values increased. From August to September values were down, increasing from September to October and October to November. These variations appear to occur in early spring continuing to summer. July to August was not significantly lower in either year. September to October showed an increase in 1974, but not in 1973. March to May measured an increase in 1973. May to June was down in both years and June to July was up in both years. These variations are thought to be due to the mixing of lake water with bay water.

TABLE 11. SANDUSKY BAY CONDUCTIVITY VALUES (micromhos/centimeter)

SANDUSKY BAY MONTHLY CONDUCTIVITY

November 1972–November 1974

Month		Mean	Maximum	Minimum	Range
Nov.	S	453	650	255	395
1972	B	455	650	365	285
March	S	417	550	330	220
1973	B	418	550	330	220
May	S	526	550	500	50
1973	B	534	600	510	90
June	S	486	570	380	190
1973	B	480	580	360	220
July	S	565	999	440	559
1973	B	—	—	—	—
Aug.	S	514	560	490	70
1973	B	—	—	—	—
Sept.	S	469	590	365	225
1973	B	—	—	—	—
Oct.	S	491	600	360	240
1973	B	—	—	—	—
Nov.	S	491	850	430	420
1973	B	524	675	340	335
April	S	503	650	350	300
1974	B	511	750	380	370
May	S	504	590	400	190
1974	B	508	610	400	210
June	S	353	410	260	150
1974	B	353	450	250	200
July	S	510	730	320	410
1974	B	511	740	320	420
Aug.	S	480	620	400	220
1974	B	496	700	390	310
Sept.	S	404	525	260	265
1974	B	413	575	280	295
Oct.	S	505	550	400	150
1973	B	509	600	425	175
Nov.	S	590	700	410	290
1973	B	592	700	410	290

SANDUSKY BAY STATION CONDUCTIVITY (micromhos/centimeter)

November 1972–November 1974

Station		Mean	Maximum	Minimum	Range
5	S	568	999	410	589
	B	497	580	340	240
17	S	490	700	350	350
	B	477	560	360	200
21	S	473	600	360	240
	B	489	650	375	275
29	S	472	540	360	180
	B	473	540	360	180
33	S	509	600	380	220
	B	529	675	440	235
35	S	466	580	355	225
	B	438	500	350	150
36	S	399	500	300	200
	B	392	500	300	200
37	S	494	580	400	180
	B	483	570	360	210
38	S	350	410	260	150
	B	362	520	250	270

Alkalinity. Alakalinity did not vary significantly from surface to bottom at any of the stations (Table 12). Significant differences were evident in comparisons between stations 38 and 33 and 38 and 5. This indicates a higher value of alkalinity entering the bay than leaving it. Alkalinity is a measure of the available carbon source, therefore it is logical to assume that the carbon is being utilized by the plankton as the water flows through the bay.

Bicarbonate is the dominant form in this system. Neither carbon dioxide nor carbonate is a major ion in this system.

Silica. Silica values were not significant surface to bottom at any station. However values were usually lower on the bottom than at the surface. This results from silica uptake by diatoms in the surface water. Comparisons of each station mean to all other station means showed station 33 to be significantly different from all stations. Station 33 had the highest mean value, 2.5 ppm silica (Table 13). Values for all other station means varied from 0.5 ppm to 1.1 ppm. Station 33 is located at the mouth of the Sandusky River. Silica entering the bay from the river may be withdrawn from the water column by the diatom population. Station 5 showed significant variation from stations 36 and 38. This may be an artifact of the sampling size. Station 5 was only sampled 3 times as compared to 9-11 times for the other stations.

Monthly mean values went down in late summer 1973 and 1974 and in the early fall of 1974. Values rose in early summer and late fall of 1974.

TABLE 12. SANDUSKY BAY ALKALINITY
SANDUSKY BAY MONTHLY ALKALINITY (ppm)
November 1972–November 1974

Month		Mean	Maximum	Minimum	Range
Nov.	S	128	170	110	60
1972	B	—	—	—	—
March	S	—	—	—	—
1973	B	—	—	—	—
May	S	—	—	—	—
1973	B	—	—	—	—
June	S	—	—	—	—
1973	B	—	—	—	—
July	S	144	291	105	186
1973	B	—	—	—	—
Aug.	S	202	393	103	290
1973	B	—	—	—	—
Sept.	S	103	120.	85.	35.
1973	B	—	—	—	—
Oct.	S	137	154.	120.	34.
1973	B	—	—	—	—
Nov.	S	145	188	120	68
1973	B	—	—	—	—
April	S	107	120	80	40
1974	B	117	170	100	70
May	S	113	120	110	10
1974	B	118	130	110	20
June	S	117	135	110	25
1974	B	117	135	110	25
July	S	117	170	100	70
1974	B	118	170	105	65
Aug.	S	129	180	100	80
1974	B	131	180	100	80
Sept.	S	125	160	110	50
1974	B	127	160	110	50
Oct.	S	136	150	120	30.
1974	B	135	155.	120	35.
Nov.	S	130	160.	110	50.
1974	B	132	160.	110	50.

SANDUSKY BAY STATION ALKALINITY (ppm)

Station		Mean	Maximum	Minimum	Range
5	S	165.	257	120.	137
	B	—	—	—	—
17	S	128.	239	100	139
	B	111	120	100	20
21	S	127.	222	80.	142
	B	116	130	100	30
29	S	150	274	103	171
	B	—	—	—	—
33	S	159	393	120	273
	B	140	170	125	45
35	S	138	376.	103	273
	B	117	125	110	15
36	S	134	291.	100	191
	B	115	120.	110	10.
37	S	138	308.	103	205.
	B	118	130.	105	25
38	S	111	171.	85	86.
	B	107	120.	100	20

TABLE 13. SANDUSKY BAY SILICA
SANDUSKY BAY MONTHLY SILIICA(ppm)

August 1973–November 1974

Month		Mean	Maximum	Minimum	Range
Aug.	S	1.2	5.2	0.4	4.8
1973	B	—	—	—	—
Sept.	S	0.5	1.0	0.2	0.8
1973	B	—	—	—	—
Oct.	S	1.2	8.5	0.3	8.2
1973	B	—	—	—	—
Nov.	S	1.1	3.0	0.7	2.3
1973	B	—	—	—	—
April	S	—	—	—	—
1974	B	—	—	—	—
May	S	0.1	0.3	0.1	0.2
1974	B	0.2	0.5	0.1	0.4
June	S	0.2	0.7	0.1	0.6
1974	B	0.4	1.0	0.1	0.9
July	S	2.1	3.4	0.2	3.2
1974	B	2.1	3.5	0.1	3.4
Aug.	S	2.1	4.0	1.0	3.0
1974	B	2.3	4.5	1.1	3.4
Sept.	S	1.2	2.6	0.2	2.4
1974	B	1.3	2.5	0.2	2.3
Oct.	S	0.6	1.1	0.1	1.0
1974	B	0.6	1.2	0.1	1.1
Nov.	S	1.3	2.0	0.5	1.5
1974	B	1.4	2.0	0.6	1.4

SANDUSKY BAY STATION SILICA(ppm)
August 1973–November 1974

Station		Mean	Maximum	Minimum	Range
5	S	0.9	1.1	0.7	0.4
	B	—	—	—	—
17	S	1.0	3.0	0.1	2.9
	B	1.4	2.9	0.2	2.7
21	S	0.8	3.0	0.1	2.9
	B	1.5	3.0	0.2	2.8
29	S	0.7	1.1	0.4	0.7
	B	—	—	—	—
33	S	2.5	8.5	0.6	7.9
	B	2.0	3.2	0.9	2.3
35	S	0.7	1.9	0.1	1.8
	B	0.7	2.3	0.1	2.2
36	S	0.5	1.3	0.2	1.1
	B	0.5	1.2	0.1	1.1
37	S	1.1	3.1	0.1	3.1
	B	1.5	3.2	0.1	3.0
38	S	0.5	1.4	0.1	1.3
	B	0.4	1.5	0.1	1.4

Dissolved Oxygen. Dissolved oxygen varied from surface to bottom at two stations, 17 and 38. Dissolved oxygen at station 33 was lower than at any other station, varying significantly from all stations. Station 33 had a mean value of 9.2 ppm. The closest value was 10.3 ppm (Table 14). Station 33 is at the confluence of South Creek and the Sandusky River. These two streams may be carrying a high biochemical oxygen demand, reducing the oxygen until sufficient mixing and aeration can take place.

The monthly dissolved oxygen was lower in the summer, beginning its decline in April, at significant levels. From July through September there were no significant variations in the monthly means. September to October to November showed significant increases occurring. This is in keeping with the changing ability of the water to hold oxygen. As the temperature increases, the saturation level for oxygen decreases, as temperature decreases saturation levels increase. At no time did the dissolved oxygen drop below the critical limit for fish life (4 ppm).

pH. Values for pH were significantly different surface to bottom at one station, 37. The remaining stations were not significantly different. Comparisons between stations indicated only 2 significant differences: station 29 to 37 and station 29 to 38. Station 29 had the highest pH while 37 and 38 had the 2 lowest values.

The pH rose significantly from August to September in 1973 and in April to May in 1974, falling significantly in May to June, 1974 (Table 15). Aside

TABLE 14. SANDUSKY BAY DISSOLVED OXYGEN

SANDUSKY BAY MONTHLY DISSOLVED OXYGEN (ppm)

November 1972–November 1974

Month		Mean	Maximum	Minimum	Range
Nov. 1972	S	10.7	11.3	10.2	1.1
	B	10.6	11.3	10.1	1.2
March 1973	S	—	—	—	—
	B	—	—	—	—
May 1973	S	13.6	16.0	12.0	4.0
	B	—	—	—	—
June 1973	S	8.8	11.0	7.0	4.0
	B	—	—	—	—
July 1973	S	13.7	21.0	9.0	12.0
	B	—	—	—	—
Aug. 1973	S	13.3	19.0	8.0	11.0
	B	9.7	18.0	7.0	11.0
Sept. 1973	S	11.0	19.5	6.4	13.1
	B	9.8	19.8	6.0	13.8
Oct. 1973	S	9.9	11.8	8.6	3.2
	B	9.5	11.2	8.0	3.2
Nov. 1973	S	11.1	14.0	9.0	5.0
	B	11.1	14.0	10.0	4.0
April 1974	S	11.6	12.2	11.2	1.0
	B	11.2	11.8	10.8	1.0
May 1974	S	10.8	12.6	10.2	2.4
	B	10.1	11.0	9.4	1.6
June 1974	S	9.7	10.8	8.8	2.0
	B	9.3	10.5	8.7	1.8
July 1974	S	8.7	9.8	7.8	2.0
	B	7.4	8.0	6.9	1.1
Aug. 1974	S	9.3	11.6	7.1	4.5
	B	7.3	11.2	5.6	5.6
Sept. 1974	S	10.0	11.2	9.2	2.0
	B	9.5	10.8	8.7	2.1
Oct. 1974	S	11.7	12.2	11.4	0.8
	B	11.7	12.2	11.2	1.0
Nov. 1974	S	12.9	13.3	12.0	1.3
	B	12.6	13.3	12.0	1.3

SANDUSKY BAY STATION DISSOLVED OXYGEN (ppm)

November 1972–November 1974

Station		Mean	Maximum	Minimum	Range
5	S	11.0	18.0	8.8	9.2
	B	10.2	18.0	5.9	12.1
17	S	10.8	16.0	7.0	9.0
	B	9.2	12.0	5.8	6.2
21	S	10.3	19.0	7.4	11.6
	B	10.1	19.0	5.8	13.2
29	S	11.6	19.5	7.1	12.4
	B	10.1	19.5	6.0	13.5
33	S	9.2	11.5	7.2	4.3
	B	8.8	11.2	6.0	5.2
35	S	10.6	19.0	7.8	11.2
	B	9.1	11.4	7.1	4.3
36	S	10.3	16.0	8.1	7.9
	B	9.1	11.3	7.1	4.2
37	S	10.4	15.0	7.8	7.2
	B	9.1	11.2	7.2	4.0
38	S	10.5	17.0	8.2	8.8
	B	8.7	11.8	6.4	5.4

TABLE 15. SANDUSKY BAY pH

SANDUSKY BAY MONTHLY pH

November 1972–November 1974

Month		Mean	Maximum	Minimum	Range
Nov.	S	8.3	8.5	8.1	0.4
1972	B	—	—	—	—
March	S	—	—	—	—
1973	B	—	—	—	—
May	S	—	—	—	—
1973	B	—	—	—	—
June	S	—	—	—	—
1973	B	—	—	—	—
July	S	7.6	8.3	7.2	1.1
1973	B	—	—	—	—
Aug.	S	7.5	7.9	6.7	1.2
1973	B	—	—	—	—
Sept.	S	7.9	8.8	6.6	2.2
1973	B	—	—	—	—
Oct.	S	7.9	8.5	6.3	2.2
1973	B	—	—	—	—
Nov.	S	7.7	8.2	6.7	1.5
1973	B	—	—	—	—
			8.0	6.8	1.2
April	S	7.4	8.0	6.7	1.3
1974	B	7.3	9.0	8.3	0.7
May	S	8.7	8.9	8.4	0.5
1974	B	8.6	8.2	7.8	0.4
June	S	8.1	8.3	7.8	0.5
1974	B	8.1	8.3	7.9	0.4
July	S	8.1	8.3	7.8	0.5
1974	B	8.0	9.9	7.6	2.3
Aug.	S	8.1	8.3	7.6	0.7
1974	B	7.9	8.4	7.9	0.5
Sept.	S	8.2	8.4	7.9	0.5
1974	B	8.2	8.3	8.1	0.2
Oct.	S	8.2	8.4	8.1	0.3
1974	B	8.2	9.1	8.0	1.1
Nov.	S	8.1	8.1	8.0	0.1
1974	B	8.0			

SANDUSKY BAY STATION pH

November 1972–November 1974

Station		Mean	Maximum	Minimum	Range
5	S	7.8	8.9	5.9	2.2
	B	7.8	8.4	6.7	1.5
17	S	7.9	8.7	6.7	2.0
	B	7.9	8.3	7.3	1.0
21	S	7.9	8.8	7.0	1.8
	B	8.1	8.9	7.0	1.9
29	S	8.1	8.7	7.6	1.1
	B	8.0	8.7	7.5	1.2
33	S	7.8	8.9	6.3	2.6
	B	7.9	8.3	7.5	0.8
35	S	7.8	8.7	6.5	2.2
	B	8.1	8.8	7.8	1.0
36	S	8.0	8.8	7.4	1.4
	B	8.1	8.7	7.5	1.2
37	S	7.6	8.4	6.6	1.8
	B	8.1	8.5	7.8	0.7
38	S	7.7	8.3	6.4	1.9
	B	8.0	8.4	7.4	1.0

(Table 15). Aside from these fluctuations, pH remained quite stable with mean surface values for all stations ranging from 7.6 to 8.1, a range of 0.5. Seasonal variation went from 7.4 to 8.7, a range of 1.2.

Nutrient Levels. Orthophosphate (PO_4) and nitrate nitrogen (NO_3) were measured from July to November, 1973. These measurements were not continued in 1974 as neither orthophosphate nor nitrate nitrogen appeared to be limiting factors to photosynthesis in Sandusky Bay. The mean orthophosphate value was 0.51 ppm. The mean value for nitrate nitrogen was 8.15 ppm. The highest values for both parameters were recorded in July. The range for orthophosphate was 0.01 to 3.60 ppm. For nitrate nitrogen the range was 0.01 to 37.0 ppm. Reid (1961) gives 0.01 to 0.03 ppm as the range for mean values of orthophosphate in most lakes. Reid (1961) gives the world average for nitrate nitrogen in unpolluted fresh waters as being 0.03 ppm. Sandusky Bay values appear to be somewhat higher than would be expected. Sandusky River values for nitrate nitrogen near Fremont ranged from 0.1 to 24 ppm from 1962 to 1965 (Ohio Department of Natural Resources, 1966). Studies currently being conducted on the Sandusky River indicate nitrate levels of 5.15 ppm and orthophosphate values of 0.076 ppm for the river above Fremont, Ohio (Baker, 1975). Sandusky Bay values are high as substantiated by the river data, however it is thought that the Sandusky Bay values are higher than they realistically should be. The method of determination may, inpart, be responsible for this. The DR-EL Hach kit was used in the determinations.

Toxic Substances. Sources of pollution are often defined on the basis of coliform counts, biochemical oxygen demand, pesticides and mercury levels. In the present study total and fecal coliform bacteria were counted and biochemical oxygen demand was measured.

Total and fecal coliform were measured in July, October and November, 1973 at stations 17, 21, 33, 35, and 37 (Table 16). These data, by above are incomplete. For the purpose of this report, additional data were obtained from the Erie County Pollution Control Laboratory. The combined data indicate that Sandusky Bay is generally within water quality standards.

Mills and Pipe Creeks exceed the water quality criteria frequently, but the coliforms apparently die before reaching the Sandusky Bay stations. The standard for primary contact (200 fecal coliforms/100 ml) was exceeded in July at stations 33 and 35. Public water supply criteria (5,000 total coliforms/100 ml) was exceeded in July at station 35. White's Landing and Bayview east ocassionally exceeded primary contact standards. This may be due to seepage from cottage septic tanks.

Biochemical oxygen demand (BOD) was measured at twelve stations from August through November of 1973 (Table 17). In Sandusky Bay oxygen loss due to BOD is not sufficient to cause an oxygen deficiency. The oxygen values from both surface and bottom did not fall below the minimum value for fish life (4 ppm) at any time during the study. The highest BOD was 10.5 ppm, the lowest was 4.1 ppm, and the overall mean was 6.7 ppm. The highest values were recorded at the mouth of Pickerel Creek, indicating an oxygen demanding load.

TABLE 16. TOTAL AND FECAL COLIFORM BACTERIA OF SANDUSKY BAY, 1973 (No./100ml)

Station	July Coliform	July Fecal	October Coliform	October Fecal	November Coliform	November Fecal
17	287	26			350	10
33	1,540	233	110	40	1,187	67
21	10,000		46	13		
35	10,000	630	6	5	5	0
37	625	12	13	3	42	10

TABLE 17. BIO-CHEMICAL OXYGEN DEMAND OF SANDUSKY BAY (PPM)

Station	Aug	Sept 1973	Oct	Nov	Mean
%5	10.5 ppm	10.4ppm	ppm	ppm	10.5 ppm
6	9.0	7.3			8.2
8	8.0	4.5			6.3
17	8800	10.2	4.1	3.9	6.6
19	5.0	6.2			5.6
21		7.5	4.1	4.84.8	5.5
311	6600	6.3			6.2
33	6.0	8.1	5.7	6.1	6.5
35	6.0	8.4	4.2	3.5	5.5
36	5.0	9.8	6.0	7.4	7.1
37	3.0	10.5	4.4		6.0
38	7.0	10.1	2.6	2.6	6.0

Pesticides and mercury in Sandusky Bay do not appear to be a problem. The Ohio EPA measured pesticide levels in the Sandusky River near Fremont. Values for April, May, July, October, November, and December, 1973, were all 0.00. Records extend back to 1967 and indicate a value for DDT of 0.01 ug/l in 1969 and 0.04 ug/l BHC in 1970 (Ohio Environmental Protection Agency, 1974). These two values were the only detectable pesticides from 1967 to 1973.

A study done by the Ohio Division of Geological Survey (1973) presents data to support the theory that mercury levels in Sandusky Bay are probably baseline. No sources of high contamination were evident. A study of mercury in chironomids and oligochaetes showed values less than 1 ppm (Walters, et al., 1974).

Conclusions. Sandusky Bay is a nutrient-rich body of water. Both orthophosphate and nitrate nitrogen are high. Conductivity is also high and alkalinity is at a level high enough to allow for high biological productivity and good buffering. Bay water pH was slightly basic. Dissolved oxygen was never below the critical 4 ppm level. Silica levels were above the 0.05 ppm level thought to be necessary for use by diatoms (McKee and Wolf, 1963). Coliform bacteria counts and BOD

The water appears to be well mixed from surface to bottom and throughout the bay. Stations 33, 36 and 38 tended to provide most of the variation indicating significant differences in water entering the bay from the river and the interface area between the bay and the lake.

BIOLOGICAL LIMNOLOGY

Phytoplankton

Two previous studies of phytoplankton in Sandusky Bay have been made. Riddle (1901) compiled a checklist of algae from Sandusky Bay. Riddle found 70 species of algae. The present study found 90 species of algae and 44 species of diatoms (Table 18).

Chandler, et al. (1938) listed 109 species of phytoplankton from Sandusky Bay during the month of August. *Aphanizomenon* comprised 70% of their phytoplankton samples. Other major genera were *Oscillatoria*, *Stephanodiscus*, *Scenedesmus*, and *Euglena*. The present study found the major components of the phytoplankton to be: *Aphanizomenon flos-aquae*, *Melosira* sp., *Asterionella formosa*, *Diatoma tenue elongatum* and *Skeletoniuma subsalsum*. The last three species were not found in the Chandler study. *Aphanizomenon* is still the single dominant species.

Phytoplankton abundance is graphed for 1974 in Figure 12. July was the peak month for phytoplankton (mainly *Aphanizomenon*). Two other peaks were evident in April and October. These peaks were composed, in April, of mainly *Skeletoniuma subsalsum* and *Melosira*, and in October, of *Aphanizomenon flos-aquae* and *Melosira*.

The Chandler study found a value of 1,201,000 phytoplankters per liter for the month of August, 1938. The present study recorded a value for August, 1974 of 30,420 phytoplankters per liter. This difference may be due to the variation in sampling techniques and sampling frequency. Chandler sampled eleven times in the month of August, while the present study sampled once. In viewing Chandler's data indications are that there is a great deal of variation between samples. The range in

TABLE 18.
PHYTOPLANKTON FROM SANDUSKY BAY

PYRRHOPHYTA

Ceratium hirudinella
Peridinium sp.

CYANOPHYTA

Anabaena sp.
Anabaenopsis sp.
Aphanizomenon flos-aquae
Chroococcus limneticus
limneticus var. *ppurpureus*
limneticus var. *subsalsus*
Gomphosphaerium apanina
lacustris
sp.
Lyngbya sp.
Merismopedia glauca
Microcystis sp.
Oscillatoria sp.
Schizothrix sp.

CHRYSOPHYTA

Botryococcus sp.
Characium gracilipes
Cryptomonas ovata
Dinobryon sertularia
sp.
Rhizochrysis sp.

EUGLENOPHYTA

Euglena acus
oxyuris
sp.
Trachelomonas sp.
CHLOROPHYTA
CHLOROPHYTA

Actinastrum hantzschii
hantzschii var. *fluviatile*
Ankistrodesmus convolutus
falcatus
falcatus var. *mirablis*
palcatus
Ankistro spiralis
Binuclearia eriensis
Characium graciliger

TABLE 18-continued

CHLOROPHYTA

Characium graciliger
sp.
Chlorella sp.
Chlamydomonas sp.
Closteriopsis sp.
Closterium acerosum var. *subpronum*
acutum var. *subpronum*
angulosum
gracileum
Coelastrum microporum
sphaericum
sp.
Cosmarium sp.
Crusigenia tetrapedia
Dictyosphaerium pulchellum
Eudorina elegans
Gleocystis planctonica
Golenkinia sp.
Hormidium sp.
Klebshormidium sp.
Lagerheimia quadriseta
wratislawiensis
Micractinium pusillum
pusillum var. *elegans*
pusillum var. *longisetum*
sp.
Microspora sp.
Mougeotia borgei
sp.
Oocystis elliptica
lacustris
Pandorina morum
Pediastrum duplex
simplex
tetras
tetras var. *tetraodon*
Scenedesmus acuminatus
arcuatus
bijugatus
dimorphus
obliqus
quadricauda
sp.
Schroederia serigera
Selenastrum sp.
Staur chaetoceros

TABLE 18-continued

CHLOROPHYTA

Staurastrum chaetoceros
paradoxum
polymorphum
Tetraedron incus
staurogeniaforme
Tetrastrum glabrum
Treubaria varia

BACILLARIOPHYTA

Achnanthes lanceolata
Amphipleura pellucida
Amphirora ornata
Asterionella formosa
Cocconeis placentula
Coscinodiscus lacustris
Rothii var. *subsalsa*
sp.
Cymatopleura solea
Diatoma tenue var. *elongatum*
Epithemia sorex
Fragilaria crotensis
sp.
Gomphoneis olivaceum
Gomphonema sp.
Gyrosigma obtusatum
scalphroides
wormleyii
sp.
Melosira sp.
Microsiphona potamos
Navicula lanceolata
sp.
tripunctata
Nitzschia closterium
holsatica
hungarica
linearis
palea
sigmoidea
sp.
Rhizosolenia eriensis
Rhoicosphenia curvata
Rhopalodia gibba
Skeletonema subsalsum (rotula)
Stephanodiscus astraea (rotula)
binderanus
sp.

TABLE-18-continued

BACILLARIOPHTA

Surirella elegans
ovata
sp.
Synedra actin
delicatissima
ulna
sp.
Tabellaria fenestrata
flocculosa

PROTOZOA

Zoothamnion sp.
Vorticella sp.
Codinella/Diffugia
Amoeboid

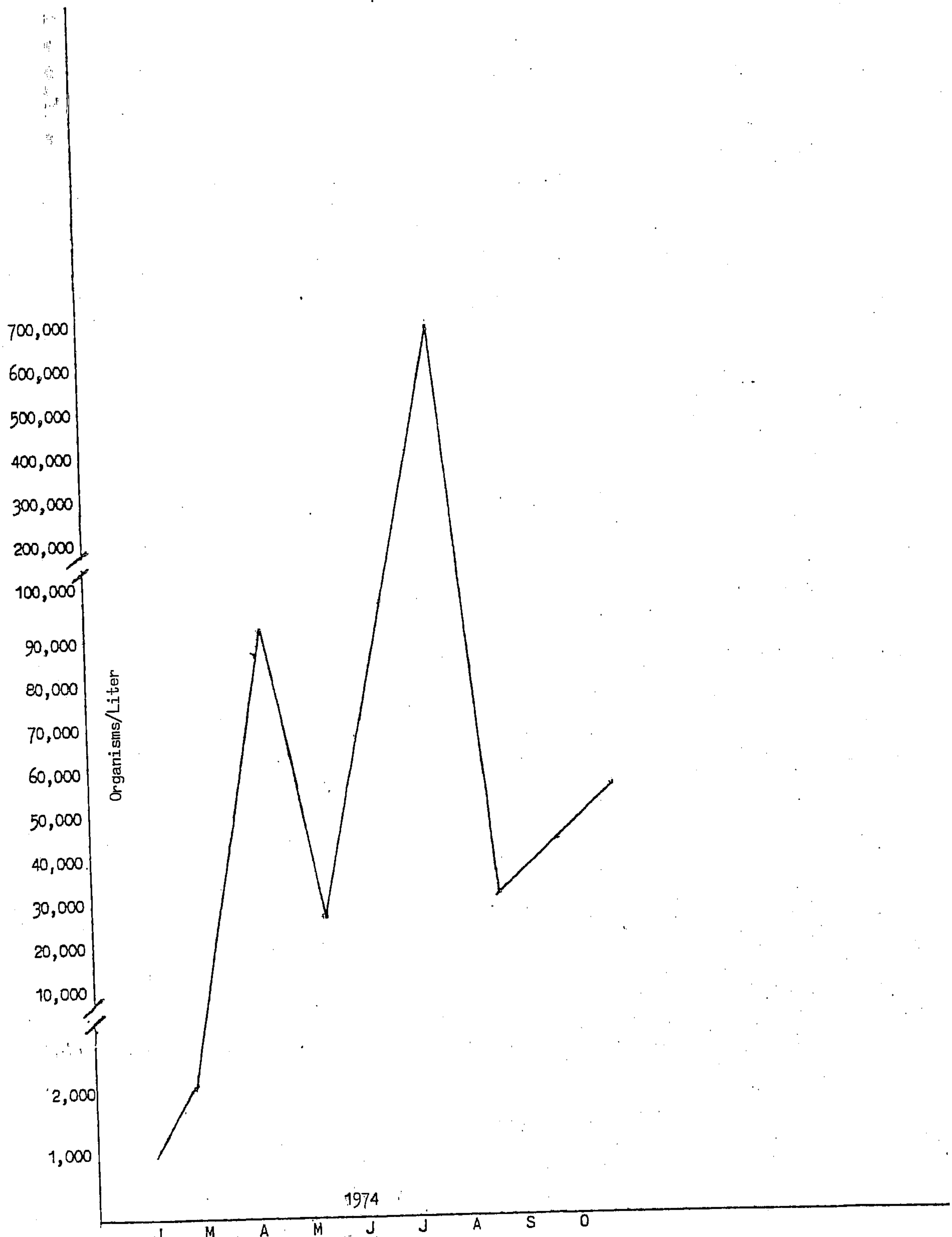


FIGURE 11. SANDUSKY BAY PHYTOPLANKTON, 1974

values is: 46,000 to 2,346,000 phytoplankters per liter. Our sample average is close to the bottom figure, seeming to indicate a decrease of some unknown magnitude.

The phytoplankton dominance hierarchy proceeded to change with time as follows: *Melosira* was dominant from January through March; *Skeletonema subsalsum* in April; and *Aphanizomenon flos-aquae* from May through October. *Asterionella* and *Diatoma tenue elongatum* were major components of the plankton from April through June.

There was no group of stations that consistently maintained a large phytoplankton population. Thirteen different stations held the top two positions each month with one duplication for each of seven stations.

Zooplankton

Zooplankton was classified into three major groups: rotifers, cladocera, and copepods.

The rotifers of Sandusky Bay were the subject of an extensive study by D. S. Kellicott in the 1890's (1896, 1897). Kellicott sampled intensively in a wide variety of habitats, limited however, to the east bay, finding a total of 106 species and forms. The present study sampled both the east and west bay with emphasis on the later. A total of 34 species, 14 genera were found (Table 19). The large difference in number of species is inpart due to the elimination of non-planktonic rotifers from our counts and identification procedures. The formalin preservative used in the samples distorts the aloricate rotifers making their identification difficult or impossible.

TABLE 19. SANDUSKY BAY ZOOPLANKTON
SANDUSKY BAY ROTIFERS

Asplanchna priodonta
sp.

Brachionus angularis
bidentatus
budapestiensis
calycifloris
caudatus
caudatus f. vulgaris
diversicornis
havanaensis
quadridentatus
sp.
urceolaris

Filinia longiseta
terminalis

Gastrophus sp.

Hexartha mira

Kellicottia longispina

Keratella cochlearis
quadrata

Monommata grandis

Notholca striata
squamula

Pleosoma truncata

Polyarthra dolichoptera
sp.
trigla
vulgaris

Pompholyx sulcata

Synchaeta sp.
stylata

Trichocerca multicrinus
similis
sp.

Unknown

TABLE 19-continued
SANDUSKY BAY COPEPODS

Copepodites/Cyclopoid
Copepodites/Calanoid

Cyclops bicuspidatus
bicuspidatus thomasi
sp.
vernalis

Diaptomus oregonensis
silicoides
sp.

Nauplii

Senecella sp.

SANDUSKY BAY CLADOCERA

Bosmina coregoni
longirostris
sp.

Ceriodaphnia lacustris
reticulata

Chydorus sphaericus

Daphnia galeata mendotae
longiremis
parrula
pulex
retrocurva
sp.

Dhydorus sphaericus

Diaphanosoma brachyurum

Eubosmina coregoni

Ledigia acanthocercoides

Leptodora kindtii

The rotifer population in Sandusky Bay is very low during the winter and early spring months (Figure 12). An average value of 12 rotifers/liter was obtained for this time period. With the advent of spring the rotifer population climbed to a high of 299 organisms/liter in June. A slow but steady decline was evident from June on through the fall samples. Diversity increased from January to a June high of sixteen species (Figure 13). Diversity, like abundance fell with the progression of time to seven species in October.

January samples were dominated by *Polyarthra vulgaris* and *Synchaeta* sp. March samples contained the still dominant *Synchaeta* sp. but a different species of *Polyarthra*. *P. dolichoptera* was the second abundant species. April samples again contained *P. vulgaris* and *Synchaeta* sp. *Branchionus calycifloris* was also an abundant species. In May *Polyarthra vulgaris* was still dominant but *Keratella cochlearis* and *K. quadrata* were also dominants. June samples contained *K. cochlearis* and *Synchaeta* sp. *Pomphalyx sulcata* was a new dominant species. *Polyarthra vulgaris*, *K. Quadrata* and *Pomphalyx sulcata* were dominant in July. August samples contained *Polyarthra vulgaris*, *Keratella cochlearis*, *K. quadrata* and *Pomphalyx sulcata* as dominant species. September samples contained *K. cochlearis*, *K. quadrata*, *Polyarthra vulgaris* and *Synchaeta* sp. October dominants were the same as September.

A limnological study of upper Sandusky Bay was done by Chandler and Bodenlos (1938). They found fourteen species and twelve genera of rotifers. The present study identified 34 species and 14 genera. Four species from Chandler et al were not found in the present study. These were:

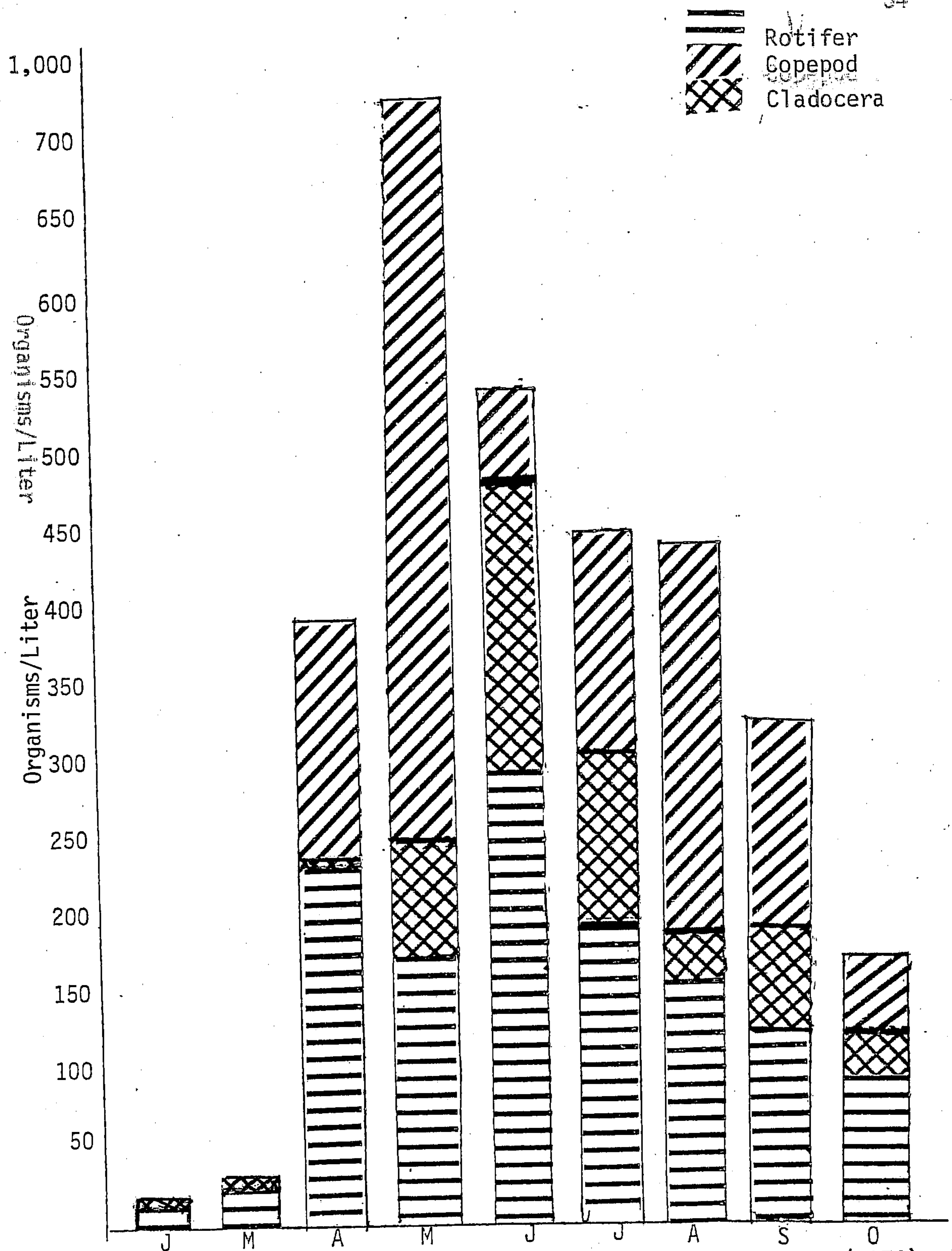


FIGURE 12. SANDUSKY BAY ZOOPLANKTON, RELATIVE ABUNDANCE (1974)

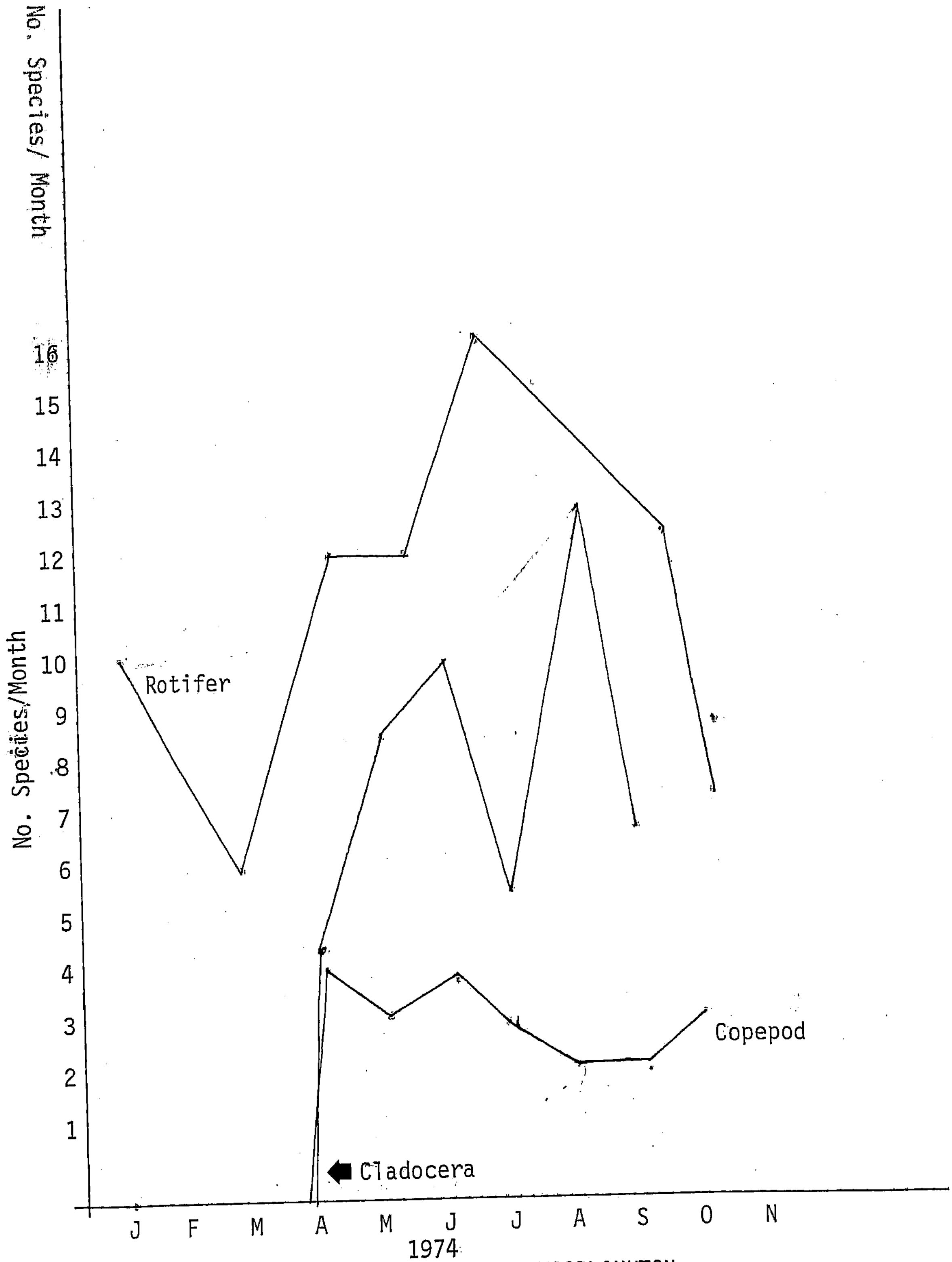


FIGURE 13. SANDUSKY BAY ZOOPLANKTON

Chromagaster ovalis, *Mytilina* sp., *Pedalia mera* (Hudson) and *Conochilus unicornis* (Rousselet). The reason for greater diversity may well be that the present study was two years in length while the Chandler, et al. study was for one month. Secondly, Chandler, et al. studied only the upper bay and not the lower bay. Most of the stations in the present study were in the upper bay, however, several were located in the lower bay. Chandler, et al. found *Branchionus*, *Keratella* and *Polyarthra* to be the dominant genera. *Branchionus* is perhaps less important at present but *Polyarthra* and *Keratella* are still the dominant genera. Chandler's value for abundance of rotifers in August, 1938, was 643.8 organisms/liter. The present study recorded a value of 168.55 organisms/liter for August, 1974. This represents a fairly substantial decrease.

Polyarthra vulgaris, *Synchaeta* sp., *Keratella cochlearis* and *K. quadrata* were the overall most abundant species in the present study.

Copepods were very low in the January and March, 1974, samples, averaging 5.8 copepods per liter (all nauplii). The copepods hit their high in May (500 copepods/liter) and declined somewhat sporadically through October (44.6 copepods/l) (see Figure 12). Nauplii dominated all samples and were found exclusively in January. By March cyclopoid copepodites were evident and *Cyclopsis bicuspidatus thomasi* was present. Both copepodites were present in April as was *Cyclops b. thomasi*, *Cyclops vernalis*, and *Diaptomus siciloides*. May and June contained the same species as April. July was the same as April except that *Cyclops b. thomasi* was no longer present. August and September were the same as July, however in October *Cyclops b. thomasi* reappeared.

Diversity went from only nauplii to nauplii, copepodites and a maximum of four species of copepod adults (Figure 13). *Diaptomus siliciodes*, and *Cyclops vernalis* were the dominant species. A total of 3 genera and 8 species were recorded (Table 19).

Chandler, et al. found only 159 copepods/ liter for the month of August, 1938. The present study recorded 215.3 copepods/liter during August, 1974. The 1938 study did not separate copepodites nor did they identify to the species level. Nauplii were the dominant copepod with the genus *Cyclops* following and *Diaptomus* present. In the present study both calanoid and cyclopoid copepodites were found in August. Nauplii was the dominant form in every month. *Diaptomus siciloides* and *Cyclops vernalis* were the most abundant species. *Cyclops vernalis* was more numerous than *Diaptomus*, but *Diaptomus* was a strong second. *C. vernalis* may have an advantage over *Diaptomus*; it reproduces throughout the year.

Nine genera and seventeen species of Cladocera were found (Table 17). The Cladocera population was not present in samples until April at which time 0.9 organisms/liter were found. Cladocera increased to a June high of 196.4 organisms/liter. This increase is in response to increased water temperature which stimulates reproduction (Pennak, 1953). The Cladocera population decreased from June to October. The October population was 23.7 organisms/liter. *Daphnia retrocurva* was dominant from April to July. July dominance was shared with *Eubosmina coregoni*. In August, *D. retrocurva* and *Chydorus sphairecus* were dominant. In October, *D. retrocurva* and *Eubosmina coregoni* were again dominant. Species diversity was erratic but two peaks were evident. The highest being in

August with twelve species, the second high being in June with nine species (Figure 13). Figure 12 illustrates seasonal variation of Cladocera.

Cladocera were far more abundant in the present study than in the Chandler, et al. study. Chandler found 4.4 Cladocera/ liter while the present study found 56.1 organisms/liter for the month of August. Six genera were named by Chandler, nine genera were found in 1974. *Daphnia* was the most abundant genus in 1938 and has maintained that position. Specifically, *Daphnia retrocurva* was the most abundant species in the present study.

Higher Aquatic Plants.

Aquatic vegetation in Sandusky Bay previous to the 20th Century was abundant and wide spread. Kellerman (1901) in a study of Sandusky Bay describes the bay as "presenting acres of *Nelumbo, Sagittaria, Potamogeton,* Rushes, Reeds, Duckweeds, *Polygonum, Ceratophyllum* and others too numerous to mention...." Moseley (1899) described the rich varied flora of the Sandusky area.

The higher aquatic vegetation of Sandusky Bay is now greatly reduced and limited to a few marshes and isolated portions of the bay. Increased turbidity, diking and draining of the marshes were the primary causes of the decline. Ronald Stuckey, in a presentation at the 1975 Sandusky River Basin Symposium, listed the higher aquatic plants of Sandusky Bay and their relative abundance. That list is given here as Table 20. One hundred and fifty species are listed. Fifty-nine species are occasional, 40 are rare and 51 are common.

TABLE 20. AQUATIC VASCULAR PLANTS OF SANDUSKY BAY

Species	Abundance
ASPIDIACEAE	
Onoclea sensibilis L. Sensitive Fern.	Occasional
SALVINIACEAE	
Azolla caroliniana Willd. Water velvet.	Rare
TYPHACEAE	
Typha angustifolia L. Narrow-leaved cat-tail.	Common
Typha latifolia L. Broad-leaved cat-tail.	Common
SPARGANIACEAE	
Sparganium eurycarpum Engelm. Bur-reed.	Occasional
POTAMOGETONACEAE	
Potamogeton crispus L. Curley pondweed	Occasional
Potamogeton foliosus Raf. Leafy pondweed	Common
Potamogeton nodosus Poir. Knotty pondweed	Occasional
Potamogeton pectinatus L. Sago pondweed	Occasional
NAJADACEAE	
Najas minor All. Naiad	Rare
ALISMACEAE	
Alisma plantago-aquatica L. Water plantain.	Common
Lophotocarpus calycinus (Engelm.) J.G. Smith	Rare
Sagittaria latifolia Willd. Arrowhead	Common
Sagittaria rigida Pursh Stiff arrowhead.	Rare
BUTOMACEAE	
Butomus umbellatus L. Flowering-rush.	Rare
HYDROCHARITACEA	
Elodea nuttallii (Planch.) St. John waterweed.	Rare
GRAMINEAE	
Alopecurus aequalis Sobol. Foxtail.	Rare
Calamagrostis canadensis (Michx.) Nutt. Blue-joint grass.	Occasional
Echinochloa crusgalli (L.) Beauv. Barnyard grass.	Common
Echinochloa pungens (Poir.) Rydb. Barnyard grass.	Common
Echinochloa walteri (Pursh) Nash Walter's millet.	Rare
Eragrostis hypnoides (Lam.) BSP. Lovegrass	Occasional
Glyceria striata (Lam.) Hitchc. Fowlmeadowgrass.	Common
Leersia oryzoides (L.) Swartz Rice-cut grass	Common
Panicum capillare L. Old-witch grass	Common
Panicum dichotomiflorum Michx. Panic grass	Common
Phalaris arundinacea L. Reed-canary grass	Occasional
Phragmites australis (Cav.) Trin. ex. Steud. Reed grass	Rare
Spartina pectinata Link Cord grass.	Occasional
Zizania aquatica L. Wild rice	Rare

TABLE 20. Continued

CYPERACEAE	
Carex aquatilis Wahlenb.	Rare
Carex atherodes Spreng.	Occasional
Carex comosa Boott	Occasional
Carex cristatella Britt.	Occasional
Carex frankii Kunth	Occasional
Cares granularis Muhl.	Rare
Carex hystricina Muhl.	Rare
Carex lacustris Willd. Ripgut.	Occasional
Carex lanuginosa Michx.	Rare
Cares stripata Muhl.	Common
Carex tribuloides Wahlenb.	Rare
Carex vulpinoidea Michx.	Common
Cypreus diandrus Torr.	Rare
Cyperus engelmannii Steud.	Rare
Cyperus erythrorhizos Muhl. Umbrella Sedge	Occasional
Cyperus esculentus L. Yellow Nut-grass	Common
Cyperus ferruginescens Boeckl. Umbrella Sedge	Common
Cyperus rivularis Kunth	occasional
Cyperus strigosus L. Nut-grass	Common
Eleocharis acicularis R. & S. Needle-rush	Occasional
Eleocharis erythropoda Steud. Spike-rush	Occasional
Eleocharis intermedia (Muhl) Schultes Spike-rush	Rare
Eleocharis obtusa (Willd) Schultes Spike-rush	Common
Eleocharis smallii Britt. Spike-rush	Rare
Scirpus acutus Muhl. Hard-stem Bulrush.	Rare
Scirpus atrovirens Willd. Dark-green Bulrush	Common
Scirpus cyperinus (L.) Kunth Wool-rush	Occasional
Scirpus fluviatilis (Torr.) Gray River Bulrush.	Occasional
Scirpus pendulus Muhl. (S.	Rare
Scripus pungens Vahl Three-square	Occasional
Scirpus validus Muhl. var. *creber* Fern. Soft stem Bulrush	Common
LEMNACEAE	
Lemna minor L. Lesser duckweed	Common
Lemna trisulca L. Star duckweed	Common
Spirodela polyrhiza (L.) Schleid Greater duckweed	Common
Wolffia columbiana Karst. Water-meal	Rare
Wolffia punctata Griseb/ Water-meal	Rare
PONTEDERIACEAE	
Heteranthera dubia (Jacq) MacM. Water stargrass.	Rare
Pontederia cordata L. Pickerelweed.	Rare
JUNCACEAE	
Juncus dudleyi Wieg. Dudley's rush	Occasional
Juncus tenuis Willd. Path rush	Common
Juncus torreyi Coville Torrey's rush	Occasional
IRIDACEAE	
Iris virginica L. var. *shrevei* (Small) E. Anders.	Occasional

TABLE 20. Continued.

SALICACEAE	Common
Populas deltoides Bartr. Cottonwood.	Occasional
Salix alba L. White willow.	Common
Salix fragilis L. Crack willow.	Common
Salix interior Rowlee Sandbar willow	Common
Salix nigra Marsh. Black willow.	Rare
Salix rigida Muhl. Stiff willow	
URTICACEAE	
Boehmeria cylindrica (L.) Sw. False-Nettle.	Common
Pilea pumila (L.) Gray clearweed.	Common
Urtica procera Muhl. Nettle.	Common
POLYGONACEAE	
Polygonum amphibium L. var. *emersum* Michx. Water Smartweed	Common
Polygonum hydropiper L. Water-pepper.	Occasional
Polygonum lapathifolium L. Dock-leaved smartweed	Occasional
Polygonum pensylvanicum L. Pinkweed.	Common
Polygonum persicaria L. Lady's thumb	Common
Polygonum punctatum Ell. Water smartweed	Common
Polygonum sagittatum L. Arrow-leaved tearthumb	Occasional
Rumex maritimus L. var. *fueginus* (Phil) Dusen Golden Dock	Rare
Rumex orbiculatus Gray Great Water dock	Rare
Rumex orbiculatus Gray Water dock	Rare
Rumex verticillatus L. Swamp Dock.	Occasional
NYMPHACEAE	
Nelumbo lutea (Willd.) Pers. American Lotus	Rare
Nuphar advena Ait. Spatter-dock	Occasional
Nupha variegatum Engelm. Spatter-dock	Rare
Nymphaea tuberosa Paine White water-lily	Rare
CERATYOPHYLLACEAE	
Ceratophyllum demersum L. Hornwort, Coon-tail	Common
RANUNCULACEAE	
Ranunculus pensylvanicus L. f. Bristly Crowfoot.	Rare
Ranunculus septentrionalis Poir. Swamp buttercup	Common
Ranunculus sceleratus L. Cursed crowfoot	Occasional
CRUCIFERAE	
Cardamine pensylvanica Muhl. Pennsylvania bitter cress	Common
Rorippa palustris (L.) Bess. var. *fernaldiana* (Butt & Abbe) Stuckey. Marsh Cress	Occasional
Rorippa palustris (L.) Bess. var. *hispida* (Desv.) Rydb. Marsh cress.	Rare
Rorippa sylvestris (L.) Bess. Creeping Yellow cress	Occasional
SAXIFRAGACEAE	
Penthorum sedoides L. Ditch stonecrop	Occasional
ROSACEAE	
Rosa palustris Marsh. Swamp rose.	Occasional
LEGUMINOSAE	
Strophostyles helvola (L.) Ell. Wild Bean	Rare

TABLE 120. Continued

MALVACEAE	
Hibiscus moscheutos L. Swamp-Rose mallow	Rare
LYTHRACEAE	
Ammannia coccinea Rothb Ammania.	Rare
Decodon verticillatus (L.) Ell. Swamp-Loosestrife.	Rare
Lythrum dacotanum Nieuw. (L. alatum Pursh) Loosestrife	Occasional
Lythrum salicaria L. Spiked Loosestrife.	Rare
ONARACEAE	
Epilobium glandulosum Lehm. Willow-herb.	Occasional
Ludwigia palustris (L.) Ell. var. *americana* (DC.) Fern. & Grisc. Water-purslane	Occasional
HALORAGACEAE	
Myriophyllum spicatum L. Water-milfoil	Occasional
Myriophyllum exalbescens Fern. Water-milfoil.	Rare
UMBELLIFERAE	
Cicuta bulbifera L. Water-hemlock	Occasional
Cicuta maculata L. Spotted water-hemlock	Occasional
PRIMULACEAE	
Lysimachia ciliata L. Loosestrife	Occasional
Lysimachia nummularia L. Moneywort	Occasional
Lysimachia thyrsiflora L. Tufted Loosestrife	Rare
Samolus parviflorus Raf. Water-pimpernel.	Occasional
ASCLEPIADACEAE	
Asclepias incarnata L. Swamp milkweed	Common
VERBENACEAE	
Phyla lanceolata Greene (*Lippa lanceolata* Michx.) Fog fruit	Occasional
Verbena hastata L. Blue vervain	Common
Verbena urticifolia L. White vervain	Common
LABIATAE	
Lycopus americanus Muhl. Water horehound	Common
Lycopus uniflorus Michx. Water horehound	Occasional
Mentha arvensis L. Mint.	Common
Physostegia virginiana L. Beth. False dragonhead	Occasional
Scutellaria lateriflora L. Mad-dog skullcap	Common
Scutellaria epilobiifolia A. Hamilton Common Skullcap	Occasional
Stachys tenuifolia Willd. Hedge-nettle	Occasional
SOLANACEAE	
Solanum dulcamara L. Bittersweet nightshade	Common
Solanum nigrum L. Black nightshade.	Common
SCROPHULARIACEAE	
Lindernia dubia(L.) Pennell False pimpernel	Occasional
Mimulus ringens L. Monkey flower	Occasional
LENTIBULARIACEAE	
Utricularia vulgaris L. Bladderwort.	Occasional
RUBIACEAE	
Cephalanthus occidentalis L. Buttonbush	Common

TABLE 20. Continued

CAPRIFOLIACEAE	
Sambucus canadensis L. Elderberry	Common
CUCURBITACEAE	
Echinocystis lobata (Michx.) T. & G. Prickly-cucumber	Occasional
Sicyos angulatus L. Bur-cucumber.	Occasional
COMPOSITAE	
Boltonia asteroides (L.) L'Her. Boltonia.	Rare
Eupatorium perfoliatum L. Bonset.	Common
Bidens cernuus L. Nodding Stick-tight.	Common
Bidens comosus (Gray) Wieg. Beggar-ticks.	Occasional
Bidens frondosus L. Beggar-ticks	Common
Eclipta alba (L.) Hassk. Yerba-de-tago.	Occasional
Helenium autumnale L. Sneezeweed.	Occasional
Xanthium strumarium L. Cocklebur.	Common

Source: Stuckey, 1975

Benthos

Twenty-eight genera of benthic invertebrates were found in Sandusky Bay (Table 21). The benthic fauna was dominated by six species, three oligochaetes and three dipterans: *Branchiura sowerbyi*, *Limnodrelus hoffmeisteri*, and *Peloscolex ferox* represented the oligochaetes. The dominant Diptera were: *Chironomus c. plumosus*, *Procladius bellus*, and *Coelotanypus scapularis*. Together these species comprise 90% of the benthic invertebrate fauna.

The benthic fauna fluctuated dramatically during the two years of this study (Figure 14). March was the month of peak abundance for the entire study as well as the 1973 sampling year. The March abundance was 4,485 organisms/meter squared. From this point the number of organisms declined dramatically to a low in August, 1973, of 457 organisms/meter squared. The benthic population increased from August, 1974, to March, 1974, after the March high, a steady decline began. The last sampling in October, 1974, showed the abundance still decreasing. The October value was 761 organisms/meter squared. Attempts have been made to correlate these fluctuations with a known physical or chemical parameter. At present, no insight into these fluctuations is available.

The benthic invertebrate fauna appeared to be homogeneous throughout the bay with three exceptions (Table 22). The exceptions are stations 33, 34, and 36. Stations 33 and 36 have mean values much higher than the mean of the means for all stations. The mean for all stations is 1,546 organisms/meter squared. The mean for station 33 is 2,279 organisms/meter squared. The mean for station 36 is 3,374 organisms/meter squared. Station 33 was at the mouth of the Sandusky River.

TABLE 21. SANDUSKY BAY BENTHOS

Bryozoa
- *Plumatella emarginata*

Hirudinea
- *Glossiphonia complanata*
- *Helobdella stagnalis*

Oligochaeta
- Tubificidae
- Immature
- *Limnodrilus hoffmeisteri*
- *Peloscolex ferox*
- *Branchiura sowerbyi*
- *Bothrioneurum vejdovskyanum*

Diptera
- Culicidae
- *Chaeoborus* sp.
- Ceratopogonidae
- *Palpomyia* sp.
- Chironomidae
- *Chironomus c. plumosus*
- *Procladius bellus*
- *Coelotanypus scapularis*
- *Polypedilum* sp.
- *Clinotanypus* sp.
- *Anatopynia* sp.

Mollusca
- Gastropoda
- *Vivaparus*
- *Amnicola*
- *Valvata*
- *Bulimnea*
- *Pleurocera*
- *Planorbis*
- *Helisoma*
- *Physa*
- *Ferrissia*
- *Goniobasis*
- Pelecypoda
- *Pisidium*
- *Sphaerium*
- *Anodonta grandis*

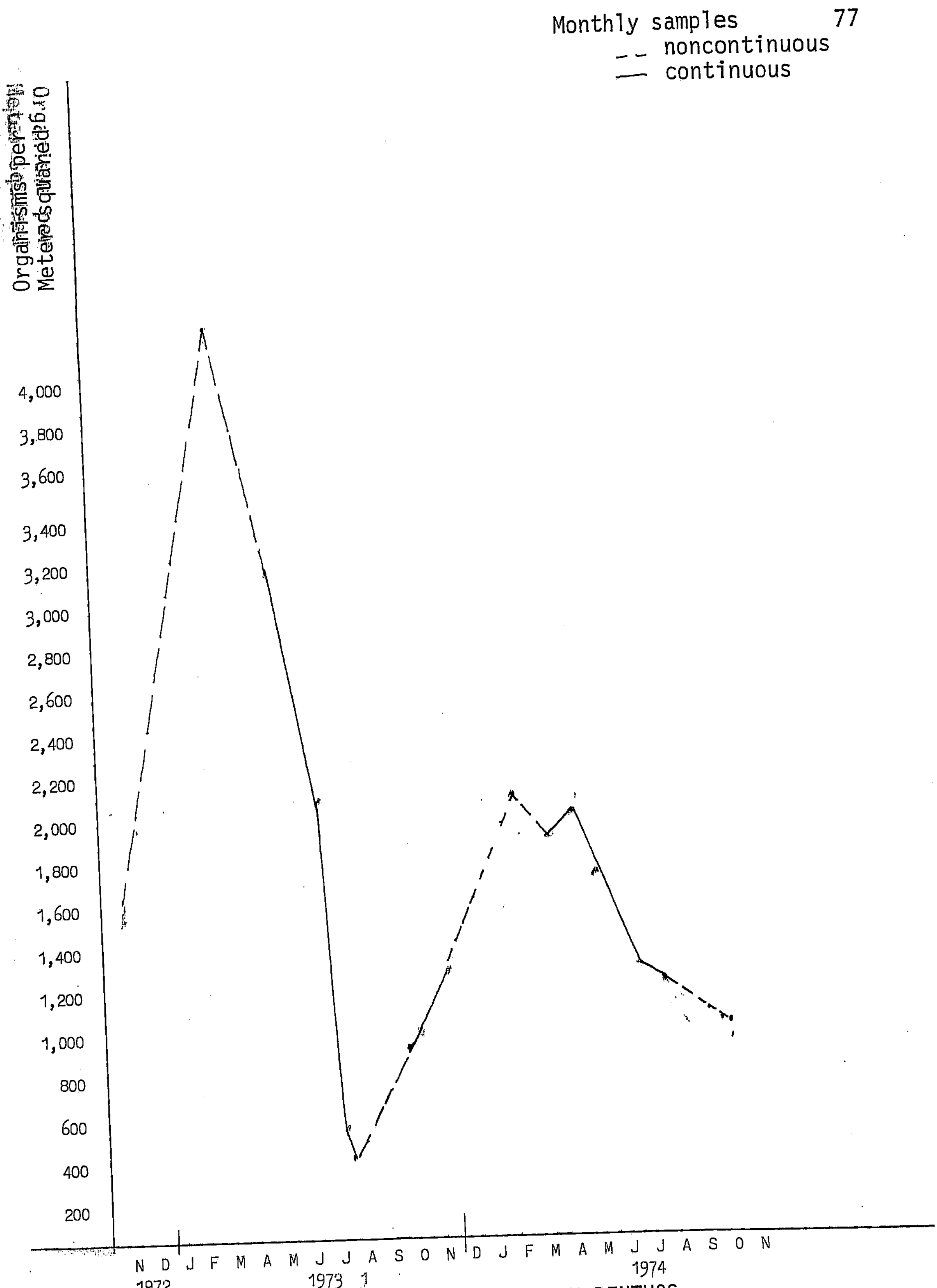


FIGURE 14. SANDUSKY BAY BENTHOS

TABLE 22.

SANDUSKY BAY BENTHOS

Total Number of Benthic Organisms Per Square Meter

Station No.	Nov. 1972	March 1973	May 1973	June 1973	July 1973	August 1973	Sept. 1973	Oct. 1973	Nov. 1973	Jan. 1974	March 1974	April 1974	May 1974	June 1974	July 1974	August 1974	Oct. 1974	X
2	3,117											1,977	1,677	1,422	1,239	1,148	795	1,625
6	2,601	3,526	1,415	497	707	496	535	632	670	825	929	2,162	2,255	1,690	1,493	1,302	843	1,322
11	1,764				1,169							2,296	1,993	1,563	1,462	1,225	863	1,541
17	976	5,977	822	572	937	421	707	1,110	1,225	1,435	1,549	1,908	1,799	1,567	1,435	1,216	813	1,439
21	632	923	1,242	593	498	229	785	1,147	1,167	1,646	1,667	2,333	2,152	1,799	1,632	1,349	958	1,221
23	1,162											1,365	1,403	1,178	1,102	994	747	1,136
29	1,243	1,118	3,113	439	249	766	1,224	1,436	1,475	1,837	1,953	1,229	1,345	1,065	886	764	574	1,218
33	387	5,891	4,279	3,464	287	191	944	1,283	1,322	1,647	1,609	2,009	1,620	1,320	1,122	1,062	739	2,279
34	172											344			298		171	246
35	1,506	645	6,475	4,249	613	478	881		1,339			2,399	2,252	1,825	1,653	1,387	1,033	1,909
36	2,970	17,673	6,150	4,077	498	709	889	1,301	1,301	6,150	6,150	2,219	2,073	1,747	1,543	1,311		3,374
37					191	363	900	1,111	1,110	1,511	1,454	2,196	1,972	1,750	1,481	1,262	835	1,241
38	2,282	129	1,679	2,467	421		1,262	1,550	1,531		1,679	2,100	2,066	1,765	1,519	1,214		1,547
X	1,568	4,485	3,147	2,045	559	457	903	1,196	1,238	1,484	2,123	1,887	1,876	1,558	1,290	1,186	761	

Mean of the Station means=1,546

Mean of the Monthly means=1,633

Station 36 was at the constriction of the bay bridges on the lower bay side. The river mouth may provide an organically enriched environment in which the Oligochaetes and Chironomids thrive. The bay bridge has a fishing area with restrooms located on it which may be a source of enrichment for station 36.

Station 34 has a mean value of 246 organisms/meter squared, a value below the mean of the means by a factor of five. This station was only sampled four times while the remaining stations were sampled with greater frequency (7-17 times). Station 34 is located at the confluence of South Creek and the Sandusky River. There may be some scour action or turbulence caused by the merger of the two streams. This scour may be the cause of the low benthic population found at this station.

The Oligochaetes were the most abundant form in the benthic invertebrate fauna, dominating the samples by 50% or more in most instances. Carr and Hiltunden (1965) found the Oligochaetes to be the most numerous taxonomic group at all but three of their 40 stations in western Lake Erie. The Sandusky Bay Oligochaetes are all of the family Tubificidae. The Tubificidae are characterized by their ability to withstand low or no dissolved oxygen for extended periods (Pennak, 1953) In the bay immature tubificids were a major component of the Tubificidae found.

The Diptera are all of the family Chironomidae. The Chironomidae and Tubificidae are typical inhabitants of highly eutrophic environments. They require a mud substrate containing a high amount of organic material.

A comparison of the present study with Chandler's 1938 study shows a similarity in organisms/meter squared. Ch[illegible]

[illegible]

A comparison of the present study with Chandler's 1938 study shows a similarity in organisms/meter squared. Chandler recorded 1450 organisms/meter squared for August, 1938. The present study recorded 1,186 organisms/meter squared for August, 1974. However, August, 1973, produced only 325 organisms/meter squared. The reason for this variation is not known. Chandler also found Diptera to be far more abundant than Oligochaetes. A shift from Diptera to Oligochaetes appears to have occurred. Chandler noted the substrate on which the organisms grew. Oligochaetes did best on silt, the Diptera on sand and gravel or clay. The muddy environment of Sandusky Bay tends to favor the occurrence of the Oligochaetes at the present time.

Fish

Introduction. Twenty three species of fish, representing 13 families were collected in Sandusky Bay from November, 1972, through November, 1974. A total of 4,882 individuals were captured during the study. Table 23 lists the species captured and the number per month of collection.

The fish population of Sandusky Bay is dominated by Gizzard shad (*Dorsoma cepedianum*) and Yellow perch (*Perca flavescens*). Gizzard shad comprised 40% of the total catch, Yellow perch comprised 22%. Other species contributing more than 1% were: White bass (*Morone chrysops*), 8.4%; Carp (*Cyprinus carpio*) and Goldfish (*Carassius auratus*), 7.4%; White crappie (*Pomoxis annularis*), 6.2%; Brown bullhead (*Ictalurus nebulosus*), 6.0%; Freshwater drum (*Aplodinotus grunniens*), 4.2%; Channel catfish (*Ictalurus punctatus*), 1.2%; and Walleye (*Stizostedion v. vitreum*) 1.0%. Figure 15 graphically illustrates these relationships.

TABLE 23.

SPECIES COMPOSITION OF FISHES TAKEN FROM SANDUSKY BAY[1]
November, 1972–November, 1974

Species	Nov. 1972	March 1973	June 1973	July 1973	Aug. 1973	Sept. 1973	April 1974	March 1974	June 1974	July 1974	Aug. 1974	Oct. 1974	Nov. 1974	Total
Longnose gar								2	17	4	2		1	26
Bowfin										2				2
Alewife							2	7	2			1	31	43
Gizzard shad	153	2	23	46	49	9	84	264	102	75	596	442	108	1953
Northern pike					1				2	1			1	5
Goldfish			3	5	2		6	10	2	24	22	8	12	94
Carp			28	14	12	4	7	33	23	48	54	19	24	266
Emerald shiner									20					20
Spottail shiner							4	19		5	4	7	1	40
Quillback		2				1					1			4
White sucker	3													3
Redhorse	1													1
Brown bullhead	111		1			2	3	4	9	72	30	74	88	294
Black bullhead				2			1							3
Channel catfish		1	4	13	5	3	7	3	1	17	4	1		59
Trout-perch							1	2			1			4
White bass	301	15		11	11	6	9	11	6	13	20	4	2	409
Largemouth bass												1		1
White crappie	11	2	5	6	6	5	11		56	26	66	56	54	304
Black crappie								18		10	5	3	1	37
Yellow perch	11	5	36	69	87	36	390	88	59	47	120	63	45	1056
Walleye	7	3	1	3	4	5	3	1	2	1	9	9	3	51
Freshwater drum	18	14	11	9	6		7	73	23	40	5	1		207
TOTAL	516	44	112	178	183	71	535	535	324	383	941	689	371	4882

[1]Captured by trawl, commercial seine, gill net, and fyke net.

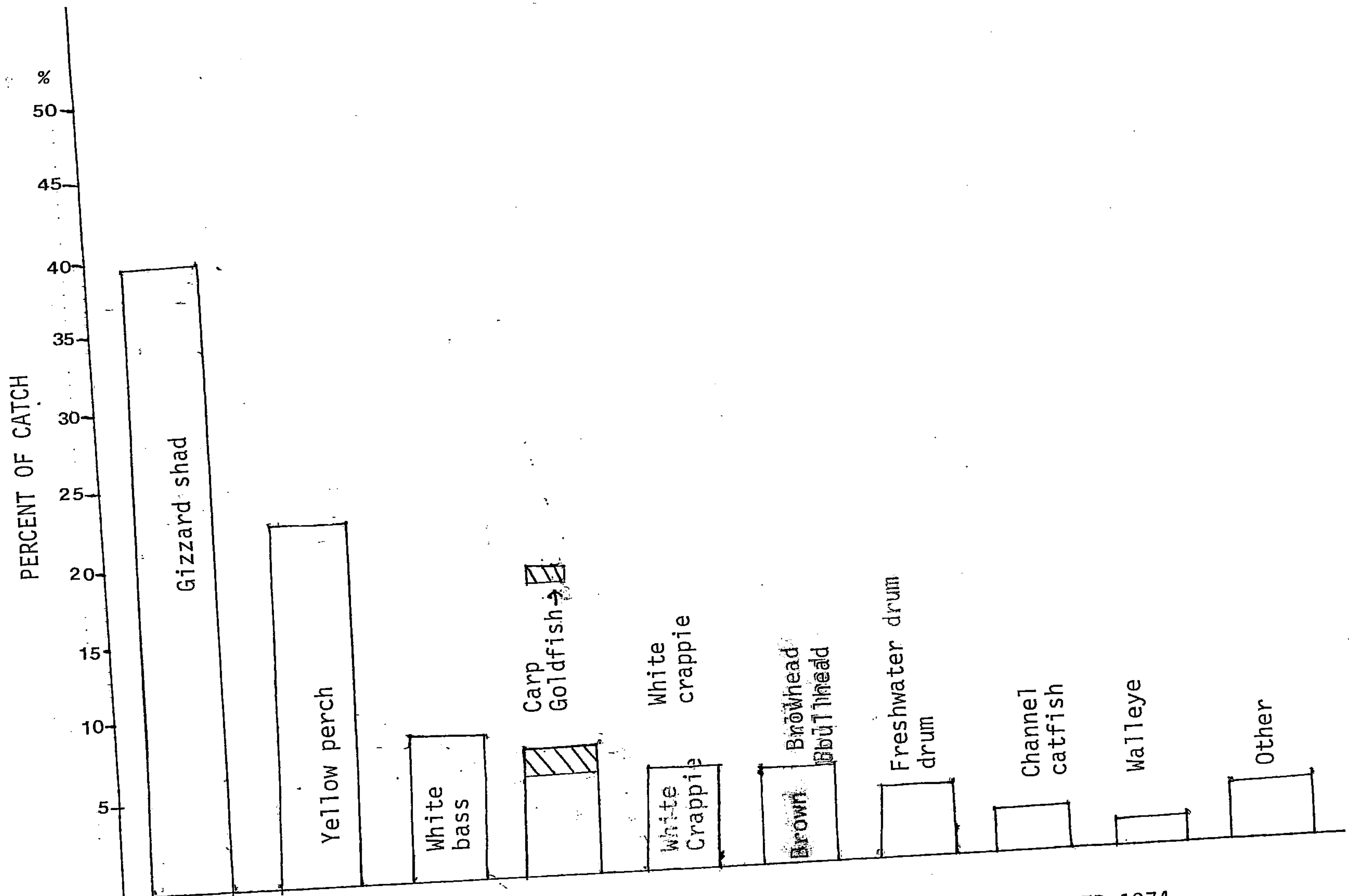


FIGURE 15. SPECIES COMPOSITION, NOVEMBER 1972-NOVEMBER 1974
(Percent of Total Catch)

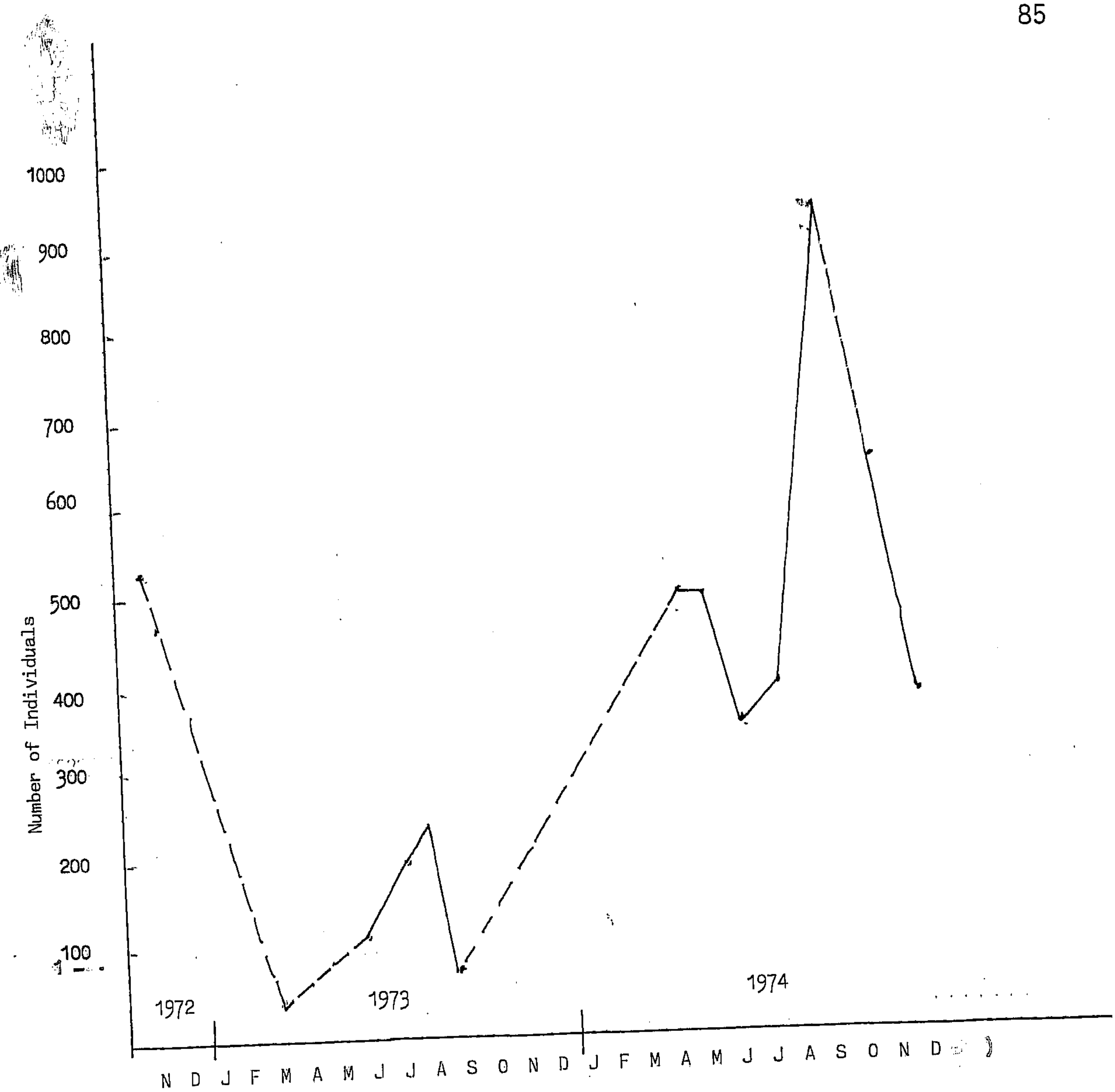
The fish of Sandusky Bay can be grouped into three catagories: rough, game and forage. In the present study the forage fish were selected against by the mesh size of the gear used. In 1973, the smallest mesh used was 1". In 1974, the smallest mesh was ½", even the ½" mesh catches only the larger forage fish. A seine with smaller mesh size could have been used to obtain samples of forage fish. This method was not used for several reasons. The main reason was the unsuitability of the bay for pulling a seine. There is much debris and many large rocks on the shore line with no location available to pull the net out of the water. Communication with Prof. Milton B. Trautman indicated that the Bluntnose minnow (*Pimephales notatus*), the Spotfin shiner (*Notropis spilopterus*), the Spottail shiner (*Notropis hudsonius*) and the Emerald shiner (*Notropis atherinoides*) are presumed present and abundant. The Emerald shiner, however, may be decreasing. In the present study only Emerald shiners and Spottail shiners were captured. Also contributing to the forage base are the young Gizzard shad. This then, is the forage base.

The game species taken in Sandusky Bay were: Northern pike (*Esox lucius*), Brown bullhead (*Ictalurus nebulosus*), Black bullhead (*Ictalurus melas*), Channel catfish (*Ictalurus punctatus*), White bass (*Morone chrysops*), Largemouth bass (*Micropterus salmoides*), White crappie (*Pomoxis annularis*), Black crappie (*Pomoxis nigromaculatus*), Yellow perch (*Perca flavescens*), and Walleye (*Stizostedion v. vitreum*). These species were 35.8% of the species composition. The rough and non-game fish taken were: Longnose gar (*Lepisosteus osseus*), Bowfin (*Amia calva*), Alewife (*Alosa pseudoharengus*), Gizzard shad (*Dorsoma cepedianum*), Goldfish (*Carassius auratus*), Carp (*Cyprinus carpio*), Quillback (*Carpoides cyprinus*), White sucker (*Catostomus commersoni*), Redhorse sp. (*Moxostoma* sp.), Trout-perch (*Percopsis omiscomaycus*) and Freshwater drum (*Aplodinotus grunniens*). These species make up 63.0% of the species composition. The remaining 1.2% are the forage fish, Emerald shiner and Spottail shiner.

Figure 16 illustrates seasonal fluctuations in the Sandusky Bay fish population. August was the peak month for both 1973 and 1974. A smaller peak occurred in April and May of 1974. Figures 17 and 18 show the close correlation between the total species abundance peaks and the abundance peaks of Gizzard shad and Yellow perch. The April-May peak is probably due to the influx of Yellow perch entering the bay to spawn. Yellow perch spawn from mid-April to May (Trautman, 1957). Also, there is an April-May peak for Gizzard shad. Gizzard shad spawn in June and July in small streams and drainage ditches (Bodula, 1964). Possibly the Gizzard shad are moving inshore, preparing to spawn in the small streams and ditches tributary to the bay. They return again in August causing a high peak in the abundance graph. A large portion of the peak is due to the influx of young Gizzard shad. The August lengths are predominantly less than 130mm. In June the lengths were between 200-400mm.

More fish were caught in 1974 than in 1973. This may be attributable to the placement of the gill net formerly at station 21 at station 5 (mouth of Pickerel Creek). Trawling was begun in 1974 replacing the fyke net and commercial shore seine. These changes may have increased the catch efficiency.

<u>Fry Tow</u>. Ichthyoplankton tows were made in Sandusky Bay from May 23, 1974 to October 24, 1974. Gizzard shad, Goldfish, Emerald shiner, White bass, Smallmouth bass, Yellow perch, Freshwater drum and various unidentifiable eggs were taken in these tows. Smallmouth bass were taken only



CAUGHT PER MONTH OF STUDY

FIGURE 16. TOTAL NUMBER OF FISH CAUGHT PER MONTH OF STUDY

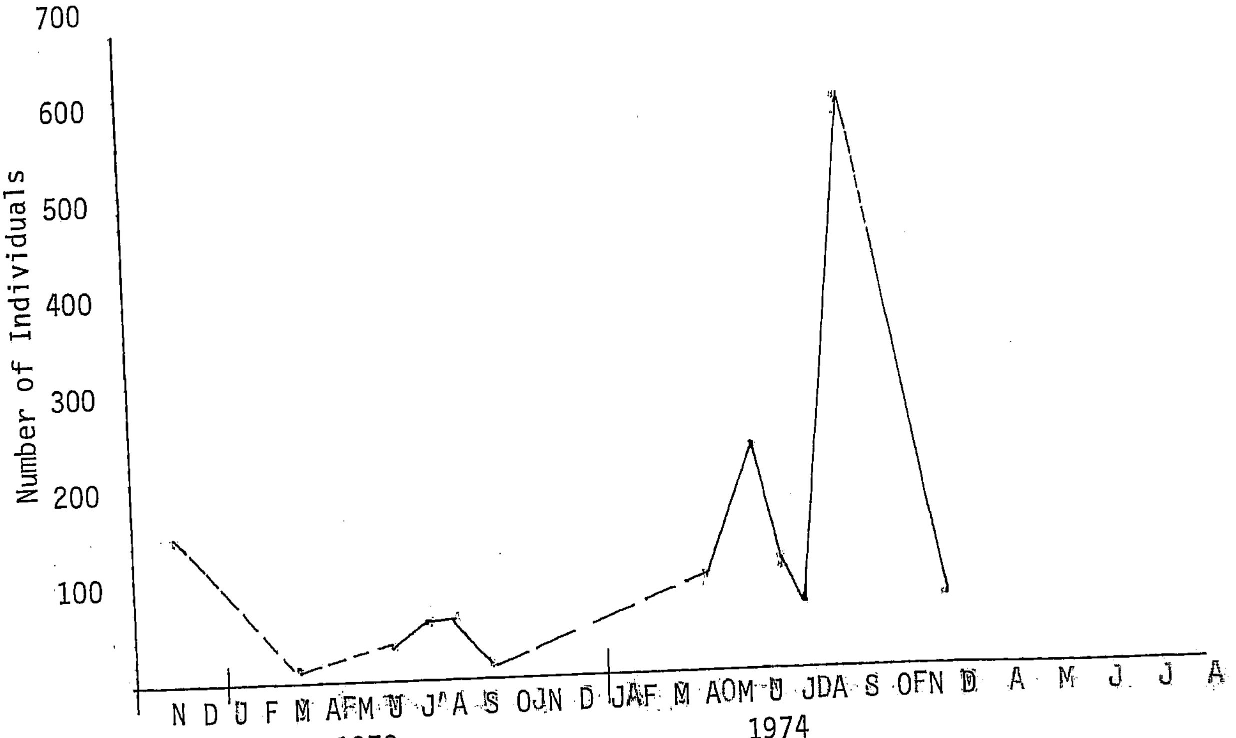


FIGURE 17. GIZZARD SHAD ABUNDANCE

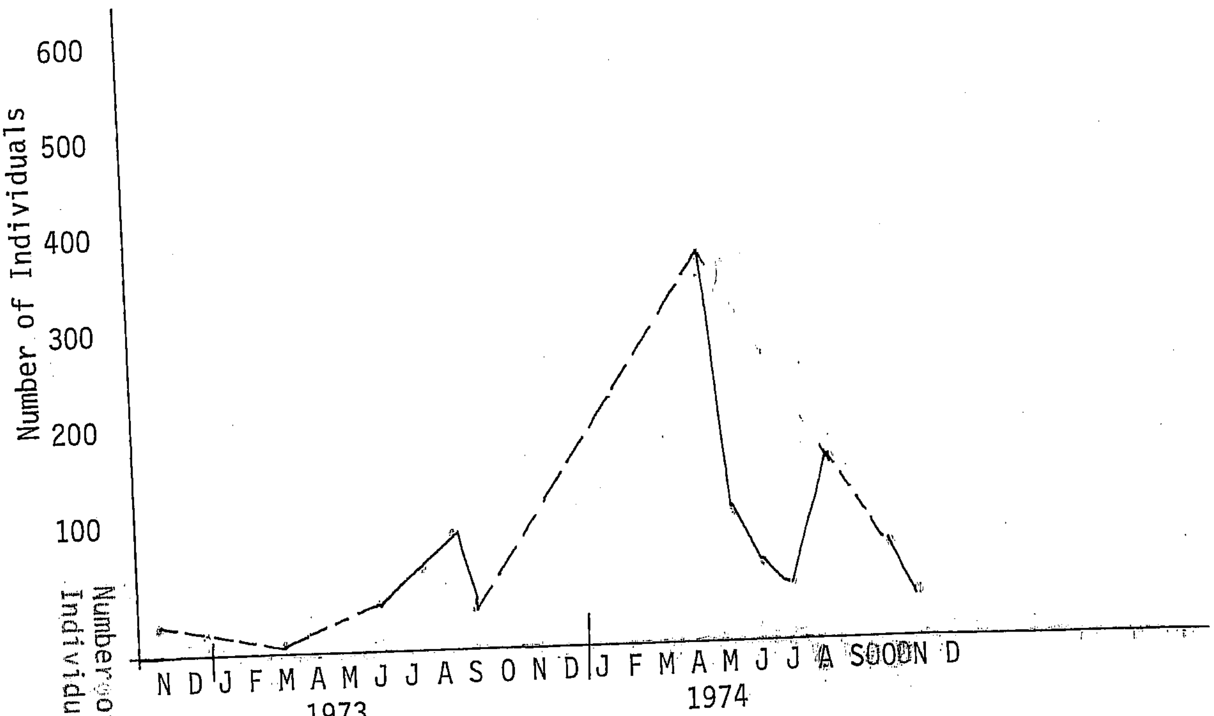


FIGURE 18. YELLOW PERCH

in the fry tows. This was to be expected as adult bass are known for their ability to avoid nets. Gizzard shad was the major constituent species in the fry tows. Unidentifiable eggs were second followed by White bass, Emerald shiner, Freshwater drum, and Yellow perch. Smallmouth bass and Goldfish contributed less than 0.1% of the total catch (Table 21). All species except for Smallmouth bass and Emerald shiner are discussed in greater detail in the Historical Section. The Emerald shiner was prominent during the month of July averaging 60.2 fry per five minute tow.

Food Habits. A total of 285 stomachs were analyzed to determine feeding preferences of Sandusky Bay fish. The species examined were Yellow perch, Black and White crappie, Channel catfish, Trout-perch, Bowfin, Carp and Goldfish, White bass, Freshwater drum, and Brown bullhead. The frequency of occurrence of food organisms in these species of fish is given in Table 25.

The most frequently occurring food organisms in Yellow perch were Diptera and fish. Price (1963) found Diptera, Amphipoda and Tricoptera to be the major food organisms of Yellow perch. Price, however, collected the fish for his 1958 study from the Bass Island area as well as from Sandusky Bay. Tricoptera and Amphipoda were not found in the bay during the present study, nor were they recorded by Chandler and Bodelas (1938). Wolfert and Hiltunen (1967) reported these organisms as present but scarce. Apparently the Sandusky Bay Yellow perch population has not changed its food habits, still feeding on the unchanged benthic population. Tubb (1973) studied the food habits of several species of Sandusky Bay fish. Tubb also found Diptera and fish to be major food items in Yellow perch.

TABLE 24. ANALYSIS OF FRY NET TOW AT SANDUSKY BAY

Species	May 31, 1974 Number	May 31, 1974 Mean *	June 26, 1974 Number	June 26, 1974 Mean	July 24, 1974 Number	July 24, 1974 Mean	Aug. 21, 1974 Number	Aug. 21, 1974 Mean	Oct. 4, 1974 Number	Oct. 4, 1974 Mean	Oct. 24, 1974 Number	Oct. 24, 1974 Mean	Total Number	%
Eggs	4,568	571	7,462	932.7									12030	28.9
Gizzard shad	27,035	3,379	740	92.5	1,228	153.5	62	7.7	7	0.9	3		29075	67.0
Goldfish			4	0.5									4	0.1
Emerald shiner					482	60.2	9	1.1	1	0.1	6		498	1.1
White bass			878	109.7	76	9.5	11	1.3					965	2.2
Smallmouth bass			3	0.4									3	0.1
Yellow perch	245	30.6											245	0.6
Freshwater drum	478	59.7	10	1.2									488	1.1
Total	32,326		9,097		1,787		82		8		9		43,309	

*Mean number per tow

TABLE 19. TABLE 25. FREQUENCY OF OCCURRENCE OF FOOD ORGANISMS IN SANDUSKY BAY FISH

Species	No. Fish	Empty	*Chironomus*	*Procladius*	*Coelotanypus*	Chironomid Larvae	Adult *Diptera*	*Oligochaete* Setae	Zooplankters	Phytoplankters	Diatoms	*Plumatella*	*Notropis hudsonius*	*Perca flavescens*	*Aplodinotus grunniens*	Unidentified Fish	Unidentifiable
Yellow perch	141	30.5	25.5	8.5	53.5	17.0	10.4	17.0	17.0	1.4	78.2	0.7	8.5	1.4	1.4	27.0	24.8
Crappies	57	19.8	38.4	8.8	3.5	26.3	0.0	12.3	26.3	1.7	1.7	0.0	5.3	0.0	0.0	12.3	35.1
Channel catfish	12	16.7	25.0	0.0	30.0	25.0	0.0	17.9	0.0	0.0	8.3	0.0	8.3	8.3	16.7	50.0	41.7
Trout-perch	3	0.0	33.3	33.3	33.3	99.9	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	010	0.0
Bowfin	1	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9	0.0
Carp and Goldfish	8	0.0	0.0	0.0	0.0	12.5	0.0	37.5	0.0	0.0	62.5	0.5	0.0	0.0	0.0	40.0	99.9
White bass	37	28.5	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	28.5	0.0	0.0	42.9	28.5
Freshwater drum	36	41.7	16.7	2.8	0.0	41.7	0.0	11.1	11.1	0.0	2.8	0.0	16.7	11.1	0.0	11.1	25.0
Brown bullhead	20	70.0	80.0	14.3	4.8	38.1	0.0	0.0	0.0	0.0	0.0	9.5	4.8	0.0	9.5	47.6	57.1

Only one Bowfin was taken in Sandusky Bay. It contained only fish. Carlander (1969) states that Bowfin feed mainly on fish and crayfish.

Carp and Goldifsh were combined because of small sample size and the close taxonomic relationship. Diatoms were found to be the major forage item with Oligochaetes of secondary importance. The basic food of the Carp is chironomids, zooplankton, and phytoplankton (Carlander, 1969). Goldfish, however, feed mostly on phytoplankton (Carlander, 1969).

White bass captured during 1974 and analyzed for food preference were found to be feeding exculsively on fish. Both Tubb (1973) and Price (1963) found fish to be the major food organism for White bass The feeding habits of the White bass do not appear to have altered since Price's study of 1958.

Freshwater drum consumed Diptera and fish during the present study. Tubb (1973) also found the Freshwater drum to be feeding primarily on Diptera and fish. Price indicates Diptera, Amphipoda, Ephemeroptera, and Cladocera as major food items. As previously stated, even at the time of Price's study, Emphemeroptera and Amphipoda were not reported as common in Sandusky Bay benthic fauna. Therefore, it is felt that there has not been a major shift in the food habits of the Freshwater drum since 1958, but there is a continuing utilization of alternate food sources. Trautman (1957) states that a shift in the food habits of the Freshwater drum occurred before 1910. Snails and clams were the principal food of the Freshwater drum but these populations have been destroyed by silting and pollution. Crayfishes, fishes and insects are now the principal food organisms.

Brown bullhead stomachs were found to contain primarily Diptera and secondarily fish. The Brown bullhead feeds primarily on insects, fish, fish eggs, molluscs and plants (Carlander, 1969). Since molluscs and plants are in short supply in Sandusky Bay, the diet of the Brown bullhead is narrowed by available forage to the Diptera and fish on which it was found to feed.

Diptera and fish appear to be major food items in the diet of the Sandusky Bay fish sampled. Oligochaetes and diatoms were also found to be important food items. This is not to imply that the phytoplankton and zooplankton are not utilized. These abundant forage items are utilized by other species of fish not sampled in this study, primarily the Gizzard shad.

Commercial Fishery. Sandusky Bay is highly productive in terms of fish harvest. The average annual commercial catch from 1938-1974 is 2,545,952 pounds. Table 26 shows the catch by species for all available years during 1938-1974. The commercial catch is illustrated graphically in Figure 19. This figure illustrates the fluctuations in the commercial harvest. The harvest is presently higher than during the 1930's and 1940's. Although down from the late 1960's the commercial catch is on another upward swing.

The commercial catch for 1973 and 1974 was 2,258,691 pounds and 2,263,222 pounds respectively. Rough fish comprised 51% of the catch in 1973 and 45% in 1974. Game fish comprised 49% of the catch in 1973 and 55% in 1974.

The important game species in 1973 and 1974 were White bass, Channel catfish, and Yellow perch. Figure 20 grapically illustrates the

TABLE 26

COMMERCIAL CATCH RECORD FOR SANDUSKY BAY*

1938–1974

	1938	1939	1948	1949	1950	1951	1952	1953	1954	1955	
Shiners	3,716	6,697	3,781	6,582	1,155	5,695	10,732	8,819	8,481		
Suckers	7,642	2,905	332,326	774,824	577,238	682,273	551,037	940,128	1,362,164		
Carp	432,874	595,990	110,005	152,860	93,053	115,608	90,500	97,094	81,475		
Goldfish	176,951	85,676	166,057	327,924	275,397	441,130	439,227	392,615	447,320		
Catfish	55,916	32,231	37,109	35,209	6,491	6,644	1,469	2,212	11,411		
Bullheads	10,787	18,299	2,251	2,515	3,514	3,208	11,526	25,300	71,452		36,238
Yellow perch	789	2,640	13,962	9,606	10,350	55,179	6,173	5,337	1,046		411
Sauger	16,453	3,545	33,989	46,428	64,038	71,482	73,322	102,154	48,804		42,860
Yellow pickerel	5,629	6,762	81,360	85,078	216,344	174,284	140,538	135,497	283,335		
White bass	38,173	17,902	865	915,184	614,458	914,479	836,928	310,965	301,317		
Freshwater drum	448,257	409,089	168		10		18,472	95	99		11
Blue pike			4	3,392	1,631	15	541	299			
Northern pike	.4			30,000	20,425	404					
Gizzard shad			5,356	5,028	3,907	17,240	10,540	7,795	3,276		
Mooneye			4,834	5,164	3,270	2,188	2,042	17,965	17,881		
Buffalo			4,300	44,300	775				49		
Bowfin			449		5		35	315	316		
Sturgeon			406	42	40	6	219	278	323		
Whitefish							170	1,972	43,280		43,280
Miscellaneous			60	1,800	163	46	480	10			
Burbot									749		
Grass Pike											
Cisco											
Smelt											
Quillback											
Total	1,197,257	1,181,736	1,658,011	2,405,936	1,892,264	2,439,881	2,193,962	2,048,854	2,639,498		122,800

*In pounds.

Source: Edminster, 1940; Chapman, 1955; Ohio Department of Natural Resources, 1950–1974.

TABLE 26—continued

COMMERCIAL CATCH RECORD FOR SANDUSKY BAY *

Continued

	1956	1957	1958	1959	1960	1962	1963	1964	1965	1966	1967
Shiners											
Suckers	3,245	10,100	1,295	10,100	6,453	14,846	21,689	15,160	10,286	6,961	9,682
Carp	1,553,013		1,889,190	1,142,311	860,673	1,088,836	936,892	1,006,333	838,603	889,978	647,371
Goldfish	142,065		156,630	94,368	285,036	258,655	159,292	151,099	167,621	134,966	94,050
Catfish	471,569		371,791	391,463	484,887	383,846	334,937	331,560	266,955	218,581	239,382
Bullheads	33,687		26,326	28,997	42,942	59,138	78,892	79,377	55,424	41,778	20,941
Yellow perch	28,117	441,643	26,534	46,023	39,128	24,238	62,874	28,841	14,468	33,966	18,703
Sauger	10	27						5			
Yellow pickerel	72,027	133,042	125,370	66,703	44,696	24,978	25,865	5,773	13,668		27,437
White bass	328,868	1	76,745	160,294	304,976	159,452	180,769	188,495	46,702	193,077	332,703
Freshwater drum	417,647	2,052,970	943,202	2,052,970	2,489,845	1,853,836	2,745,371	2,076,114	1,800,486	1,259,514	1,595,028
Blue pike		18									
Northern pike											
Gizzard shad					3,522	2,324	150	255	1,140	5,375	
Mooneye	1,396		422	523	1,242	588	657	214	56		
Buffalo	26,347		12,663	3,071	6,059	12,293	9,778	23,206	12,849	8,845	8,619
Bowfin											
Sturgeon	101			15				69	1,521	43	
Whitefish		2,831	522	3,375				69	1,521	25	33
Miscellaneous	18,122	961	555	961							3,618
Burbot	25	745	1,484					15	129		
Grass pike											
Cisco	750									286	
Smelt						40					
Quillback											
Total	3,096,989	178,305	3,659,055	4,282,174	4,529,442	3,883,030	4,557,066	3,916,486	2,464,343	2,779,049	2,972,877

*In Pounds.

TABLE 26–continued

COMMERCIAL CATCH RECORD FOR SANDUSKY BAY*

Continued

	1968	1969	1970	1971	1972	1973	1974	Mean[1]
Shiners								5,207
Suckers	28,146	23,605	43,326	31,020	25,555	45,462	13,938	13,693
Carp	752,478	972,835	1,470,322	912,211	802,754	726,615	691,002	911,972
Goldfish	991,459	82,712	156,390	76,281	30,690	26,158	52,597	121,449
Catfish	291,298	276,529	176,898	193,513	149,319	78,753	80,206	275,097
Bullheads	8,983	22,249	17,164	21,657	9,185	9,576	11,192	25,885
Yellow perch	27,113	53,772	32,238	27,395	5,564	17,387	9,400	31,885
Sauger								2,005
Yellow pickerel	35,845	17,949	7,998			11,415		40,971
White bass	156,887	394,846	294,970	184.949	55,662	986,737	1,143,081	219,251
Freshwater drum	2,540,353	1,584,554	659,822	441,982	319,596	336,221	234,205	1,047,882
Blue pike								726
Northern pike								226
Gizzard shad								2,446
Mooneye	37	17						2,242
Buffalo	18,312	7,813	7,267	2,347	494	8,887	8,945	8,890
Bowfin								395
Sturgeon								1,140
Whitefish	186							1,899
Miscellaneous	269	440	2,350					1,107
Burbot								1,855
Grass pike								29
Cisco								40
Smelt						200	4,849	189
Quillback					1,144	11,460	13,807	1,016
Total	4,116,366	3,437,321	2,868,745	1,981,360	1,399,963	2,258,691	2,263,222	

[1] The means were calculated using only the data from 1948–1974.

*In Pounds.

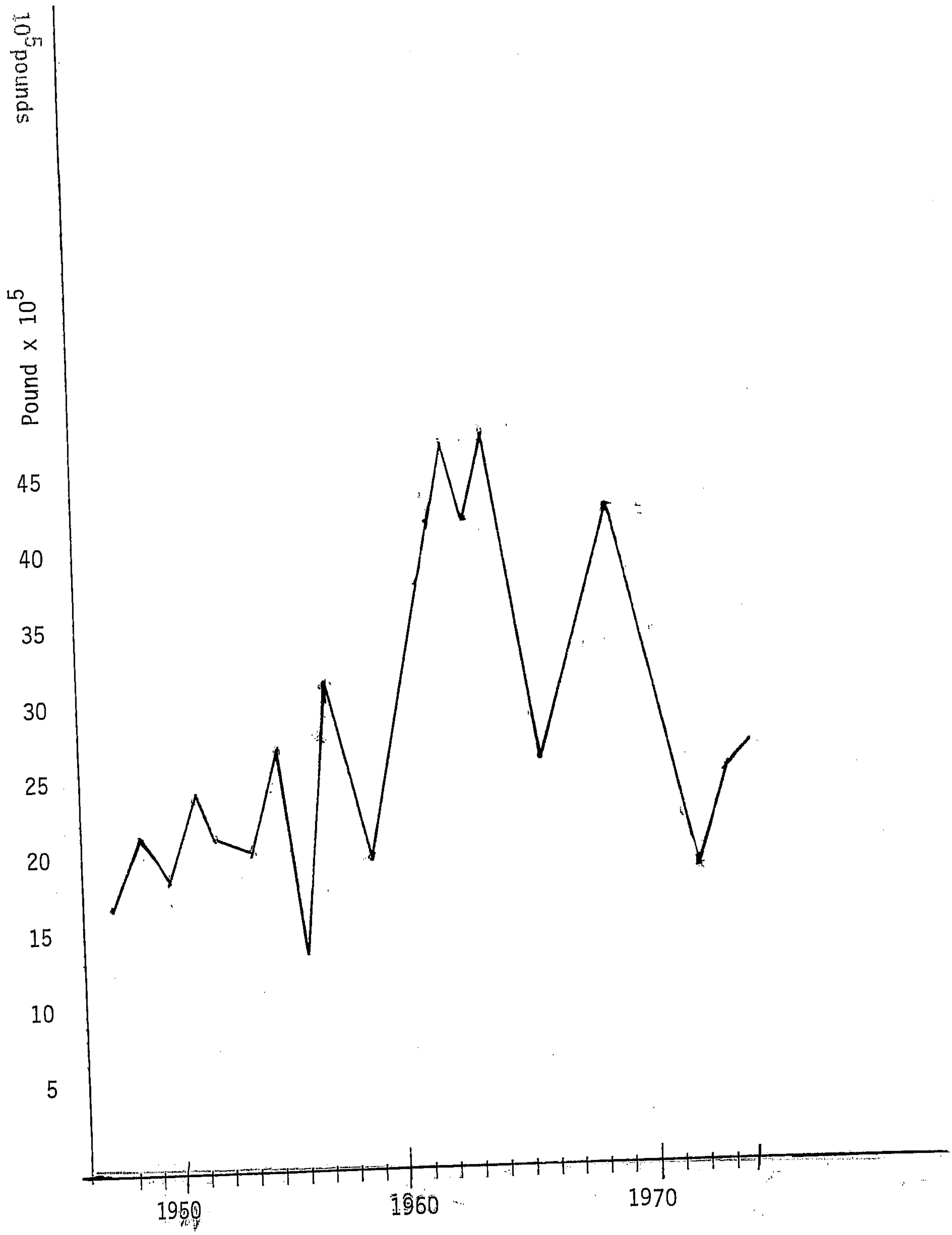


FIGURE 19. TOTAL COMMERCIAL CATCH OF FISH (1948-1974)

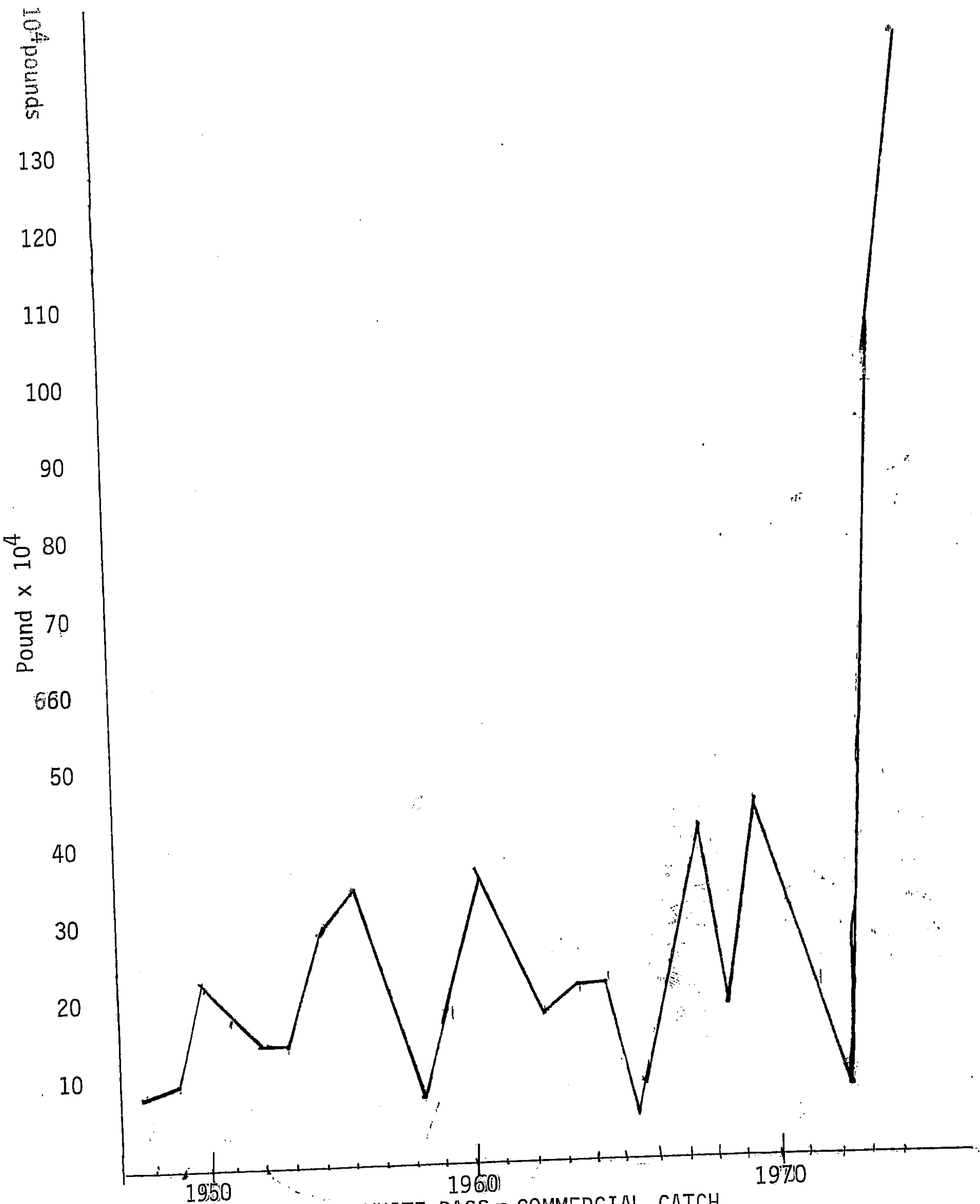


FIGURE 20. WHITE BASS, COMMERCIAL CATCH
(1948-1974)

commercial catch of White bass. There are fluctuations in the catch record but the population appears to be relatively stable until 1972-1974 when a tremendous increase occurred, more than doubling the commercial catch.

The commercial catch of Channel catfish was lower in 1973-1974 than it has been since 1948 (Figure 21). The Channel catfish appears to have prospered during the 1950's then slowly declined through the 1960's and early 1970's.

The Yellow perch population, as reflected by the commercial catch records, has fluctuated dramatically (Figure 22). The 1930's and 1940's show a low stable population increasing in the 1950's proceeding to peak and drop roughly every three years from 1952 through 1974. The Yellow perch is an unstable population subject to large scale drops. The population appears to be under environmental stress with a brood stock not large enough to compensate for a bad year class.

The important rough species for 1973 and 1974 were: Freshwater drum Carp, Sucker, and Goldfish. The Freshwater drum catch has fluctuated markedly (Figure 23). This may represent a true change in the fish population or be due to a low market demand. Trautman (1957) states that during 1939-1949, the poundage of Freshwater drum captured was far greater than the demand, and the unmarketable excess was returned to the water.

The commercial catch of Carp, like the Freshwater drum, depends on market demand. The Carp has numerous peaks in its commercial catch record (Figure 24). However, the Carp appears to be more stable than the Freshwater drum. The increases and decreases are not so dramatic as with

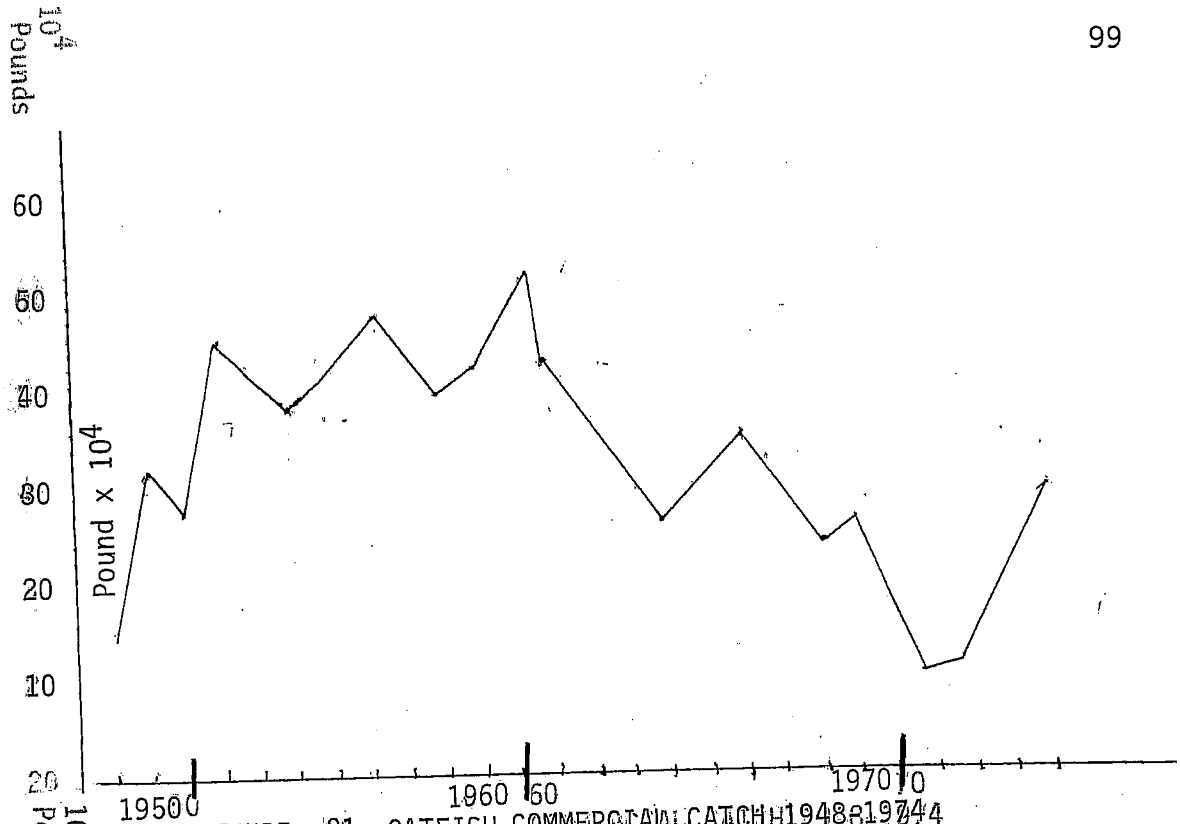


FIGURE 21. CATFISH-COMMERCIAL CATCH 1948-1974

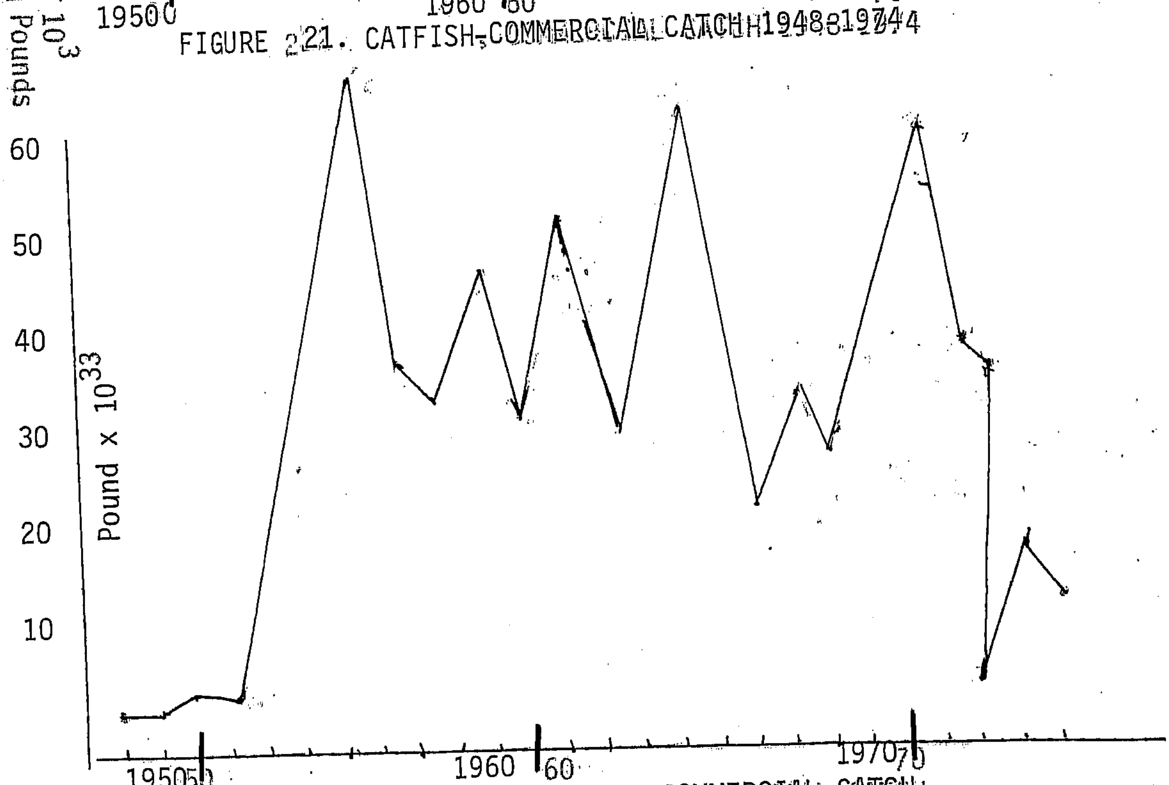


FIGURE 22. YELLOW PERCH-COMMERCIAL CATCH
(1948-1974)

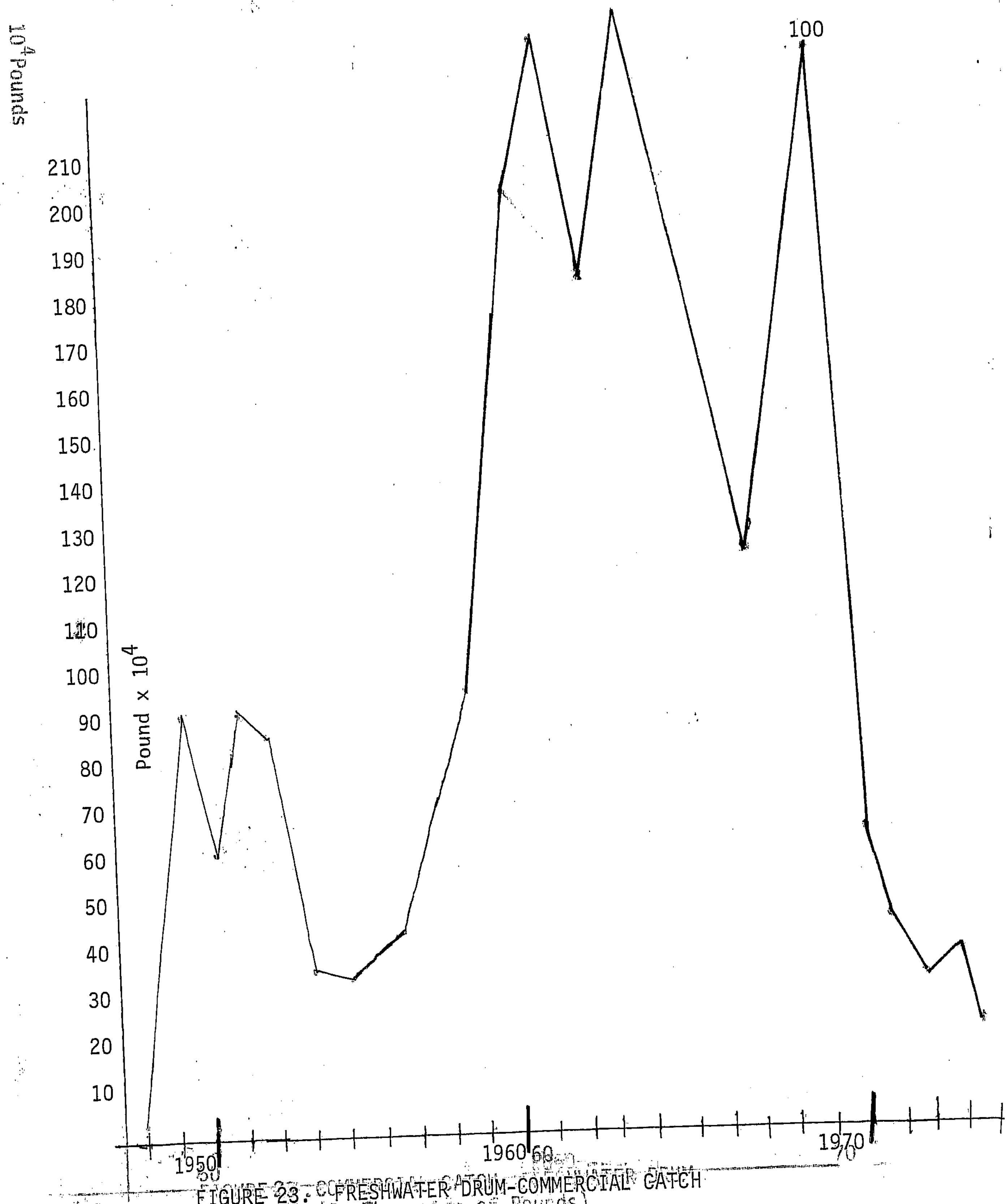


FIGURE 23. FRESHWATER DRUM-COMMERCIAL CATCH
(In Thousands of Pounds)
(1948-1974)

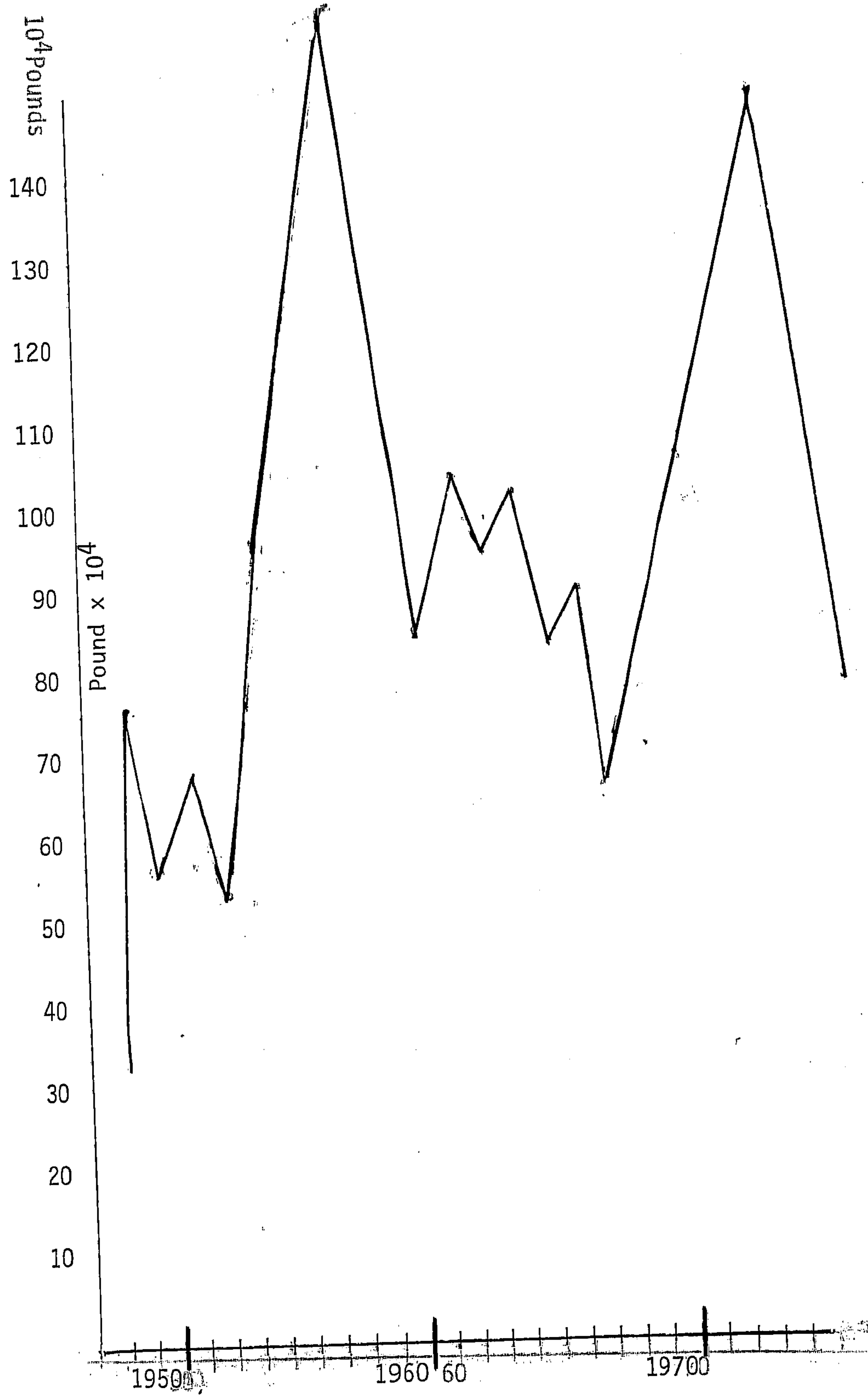


FIGURE 24. CARP-COMMERCIAL CATCH (1948-1974)
(In Thousands of Pounds)

the Freshwater drum, perhaps indicating greater stability in the carp population or market. Both the Carp and the Freshwater drum are consistent contributors to the commercial catch and do not appear to be declining.

The Goldfish (Figure 25) has maintained a stable population until 1971 when it fell to a record low, hitting bottom in 1973. The 1974 catch was up. The population is again stabilizing around the 100,000 pounds/year mark.

The Suckers were a fairly stable contributor to the commercial catch until 1967 when the catch increased by two-fold (Figure 26). The increasing trend continued until 1974 when the catch fell back to the 1967 level. The Suckers and Goldfish appear to be fairly stable. The fluctuations, which are evident, may be due to market demand.

A comparison between Sandusky Bay and the Ohio waters of Lake Erie shows that Lake Erie contains 881,758 hectares while Sandusky Bay contains only 89 hectares (Chapman, 1955). If Sandusky Bay and the Ohio waters of Lake Erie were combined, 2% of the final figure would represent Sandusky Bay while the remaining 98% would represent the Ohio waters of Lake Erie. The combined commercial catch for Lake Erie and Sandusky Bay in 1973 was 7,429,857 pounds, and in 1974, 8,728,211 pounds (Ohio Department of Natural Resources, 1974 and 1975). Sandusky Bay was responsible for 2,258,691 pounds in 1973 and 2,263,222 pounds in 1974. Thirty percent of the 1973 catch and 26% of the 1974 catch came from Sandusky Bay, making that 2% of the total area a very productive body of water.

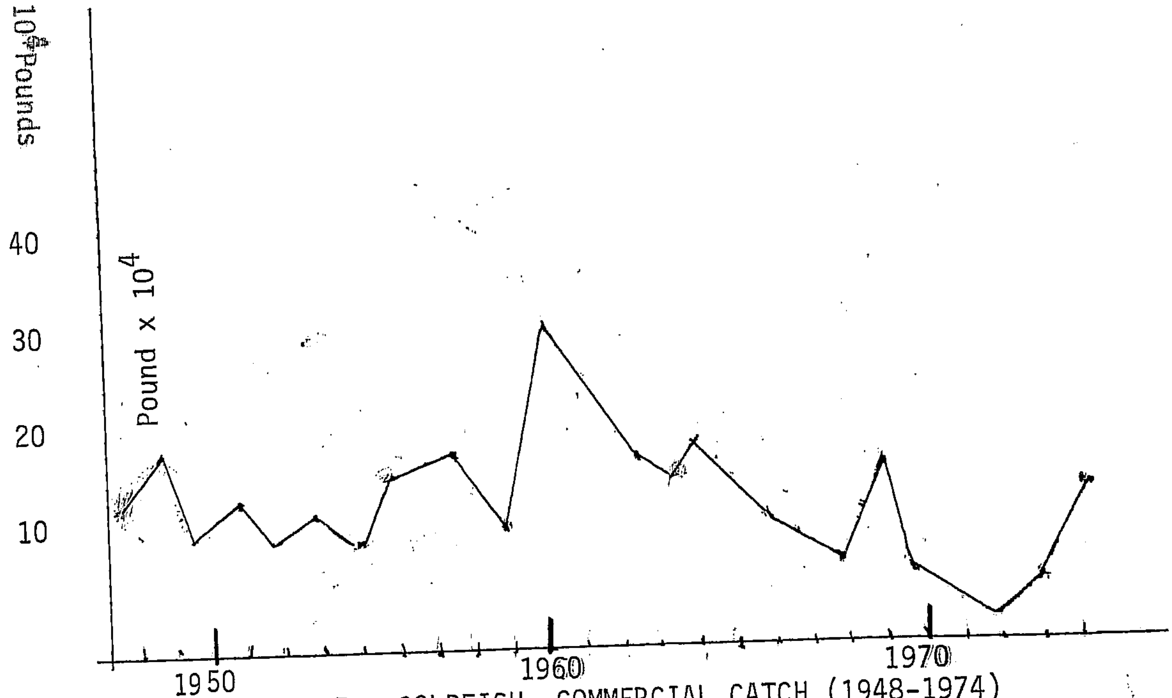


FIGURE 25. GOLDFISH,-COMMERCIAL CATCH (1948-1974)

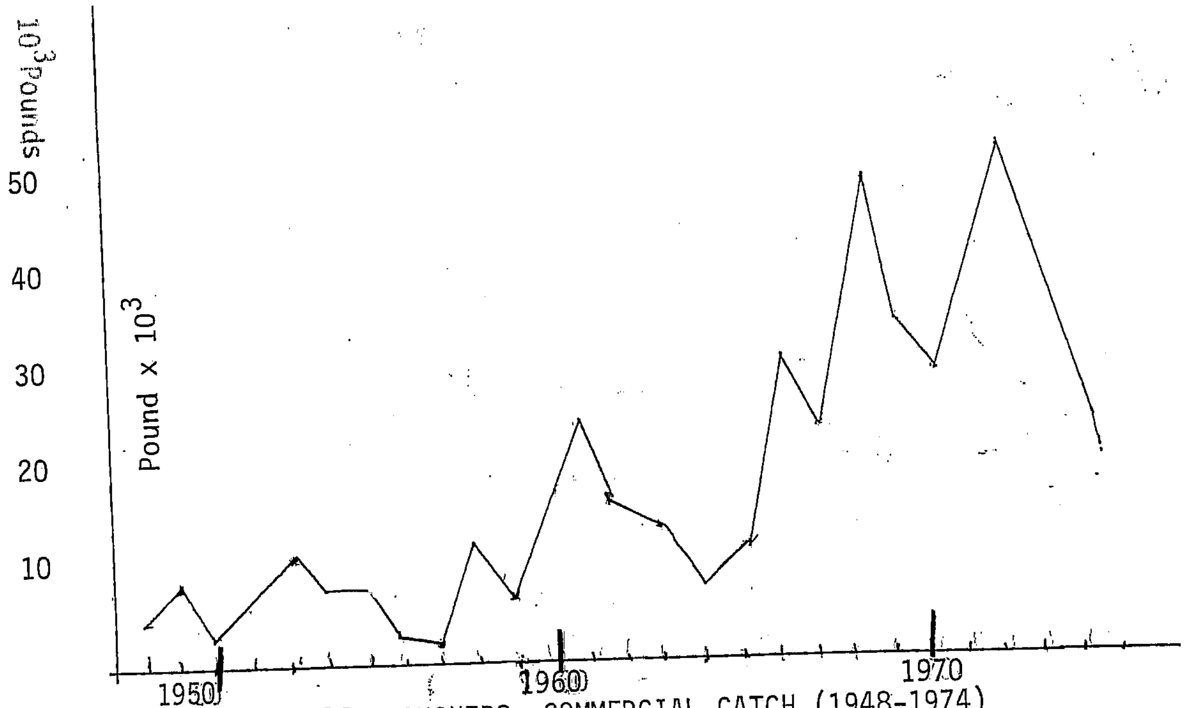


FIGURE 26. SUCKERS,-COMMERCIAL CATCH (1948-1974)

Historical Discussion. The fish population of Sandusky Bay has undergone a dramatic change in response to increased environmental stress. Factors that have contributed to this environmental stress are: deforestation, plowing of virgin prairie, diking of marshes, ditching and draining of land, construction of mill dams and in 1910 the Ballville Dam, intensified commercial fishing and the introduction of exotic species.

These environmental changes were just beginning to have an impact on the Sandusky Bay fishery in the 1870's. In 1877 Klippart, writing about the 1830's Sandusky fishery in his annual report to the Ohio Fish Commission listed White bass, Walleye, Northern pike, Muskellunge, Catfish, and Blackbass as the most abundant fish species in Sandusky Bay.

A comparison of species abundant in 1830 to species abundant in 1940 and 1974 shows a dramatic change in species comprising the fish population in the last century and a half (Table 27). From 1940 to 1974 the change is one of relative abundance.

TABLE 27. COMPARISON OF FISH SPECIES ABUNDANCE

1830[1]	1940[2]	1975[3]
White Bass	White crappie	Gizzard shad
Walleye	White bass	Yellow perch
Northern pike	Gizzard shad	White bass
Channel catfish	Carp and Goldfish	Carp and Goldfish
Largemouth bass	Bullheads	White crappie
Muskellunge	Freshwater drum	Bullheads
	Channel catfish	Freshwater drum
	Black crappie	Channel catfish
		Walleye

Species listed in decreasing abundance.

[1]Klippart, 1877
[2]Edminster, 1940
[3]Present Study

The decline of the once abundant Northern pike and Muskellunge was caused by several factors. The mill dams built during the early 1800's blocked the upstream migration. The draining and diking of marshes removed spawning habitat, and by 1900 the commercial fishing pressure on these two species (first to become commercially important) was intense. The increased turbidity and decreased aquatic vegetation furnished the final blow to the Northern pike and the Muskellunge (Trautman, 1957). The Muskellunge has become so severely depleated in Sandusky Bay and Lake Erie, that it is considered to be an endangered species (1974) by The Ohio Division of Wildlife, Chief, Division of Wildlife, Dan C. Armbrewster.

Both the Smallmouth and Largemouth bass were commercially important species in 1830, and were very abundant until the 1900's. In 1902, commercial fishing for these species was prohibited (Trautman, 1957). The Largemouth and Smallmouth blackbass are presently common and uncommon respectively (Willis, 1974).

Trautman lists turbidity, dams, and silting over of firm bottoms as the major reasons for the decline of the Walleye. The Walleye was still entering the commercial catch in the 1930's, in small numbers. The catch increased in the early 1950's and has declined since then. The Walleye presently provides a basis for an intense sport fishery. Edminster (1940) and Chapman (1956) found that the Walleye entered the bay in large numbers in the spring, but did not remain there long. The 1972-1974 information indicates a small number of Walleye was present in the bay. It is felt that this information represents a small resident population or stragglers and that the large spawning run was missed.

The White bass has gone from the most abundant species in the bay to a lower position on the abundant species list. The White bass is a highly migratory species preferring clear water, firm bottoms, an abundance of small fish and a depth of less than 30 feet (Trautman, 1957). The depth requirement is obviously met in Sandusky Bay and the abundance of small fish is fairly certain. However, the clear water and firm bottoms are conspicuously absent. Despite this combination of favorable and unfavorable factors, the White bass appears to be holding stable and has increased in pounds taken commercially over the last forty years. Young of the year White bass were taken in Sandusky Bay in June, July, and August of 1974. The June trawls yielded 110 young per five minute tow, the largest catch.

The Channel catfish prefers clean bottoms, deeper or larger waters, but will tolerate silt providing the rate of deposition is low (Trautman, 1957). It does not require aquatic vegetation. Apparently that its tolerance of silt and its lack of dependency on aquatic vegetation have allowed it to continue and maintain the population in Sandusky Bay. Edminster (1940) and Chapman (1955) found the catfish to be a seasonal member of the community structure, present in the spring and returning to the lake in the summer or fall.

The White crappie is presumed to have been common before the 1900's. As the Walleye, Northern pike and Muskellunge decreased, the White crappie increased. The White crappie is tolerant to a wide variety of habitats, especially turbid water. Turbid conditions in the bay favor the White crappie over the Black crappie. This is evident in Edminster's study (1940) and the present study. Black crappies were caught on a ratio of 1 to 100 and 1 to 10 respectively. The White crappie fell from comprising 72% of the 1940 catch to 8.4% of the 1972-1974 catch. This may be due to a decline in the White crappie population, an increase in the other more abundant species (Gizzard shad and Yellow perch) or to differences in sampling technique.

The Gizzard shad was not mentioned by either Klippart or Edminster. Trautman indicated that the Gizzard shad was probably present before the 1900's. By 1974 the Gizzard shad had become abundant. The Gizzard shad favors turbid waters where there is an abundance of phytoplankton. Sandusky Bay satisfies both of these habitat preferences. Phytoplankton is greatest in July with an average value of 623,287 organisms per liter. The Gizzard shad has not been taken commercially since 1966 and is considered to be an under utilized resource. Young of the year Gizzard shad were taken in large numbers in 1974. The greatest catch was in May when 3,300 individuals were caught per five minute tow.

The Carp was introduced into Lake Erie waters in 1879. The Goldfish was introduced in 1888. The Carp and Goldfish were listed by Edminster (1940) as being permanent residents of the Sandusky Bay fish community, seldom migrating out. The Carp is tolerant of pollution and various types of bottoms. The Goldfish is more dependent on aquatic vegetation and is less tolerant of pollution and turbidty. Both species have increased rapidly and are presently abundant. Young of the year Goldfish were caught in June of 1974 and comprised 1% of the total ichthyoplankton catch (less than one fish per five minute tow).

The Yellow perch prefers clear water and rooted vegetation. The Yellow perch normally decreases with increased turbidity. Yet it has remained abundant in Sandusky Bay. The Yellow perch is seasonal, moving in with spring and out during the summer and back in the fall to be a primary contributor to the winter fishery (Chapman, 1956). Young of the year Yellow perch were caught in Sandusky Bay in May, 30 individuals per five minute tow.

The Freshwater drum was abundant before 1860 and remained abundant through 1950 according to Trautman (1957). Edminster supports Trautman's statement and the 1972-1974 information indicates it is still abundant. The Freshwater drum can tolerate turbid water and is capable of adjusting its food habits to available forage (the Freshwater drum shifted from snails and molluscs to fish, insects and crayfish). The Freshwater drum is so abundant in Sandusky Bay that the 1970 Ohio Revised Code contains the following law (1533.56): "Carp and sheepshead may be taken from Sandusky Bay to improve the habitat for other fish and provide a better balance of fish in Sandusky Bay, Carp and Sheepshead of any length may be taken, caught, possessed, bought and sold from within Sandusky Bay. Such fish may be taken and caught only in the manner provided by law...."

Young of the year Freshwater drum were taken in icthyoplankton trawls in June and May with the greater number being taken in May (10 and 478 young respectively). In 1956 Chapman found the Freshwater drum composed 6.7% of the hatch of the year.

Bullheads were not mentioned in Klippart's report but Trautman (1957) indicates that all 3 species were abundant before 1900. Edminster's (1940) information lumped the bullheads together into one count. However, he stated that Brown and Black bullheads occurred in a ratio of 2:1. In the present study Brown bullheads were found to the virtual exclusion of the Black bullheads. Yellow bullheads were not mentioned in Edminster's work and were not taken in the present study. Bullheads as a group are often referred to as being tolerant of adverse conditions (Lagler, 1956). Both the Brown and the Black bullhead are presently considered to be common (Willis, 1974) but the Yellow bullhead is decreasing. The Yellow bullhead is the least tolerant of turbid conditions, and was already decreasing in 1957 (Trautman). The Black bullhead is more tolerant than the Brown bullhead, yet less than 1% of the bullheads caught were Black bullheads. Trautman (1975) discussed the possibility of the "Brown bullheads" really being intergrades of Brown and Black bullhead crosses. Trautman indicated that the Brown and Black bullhead hybrid is fertile.

Status and Trend of Sandusky Bay Fish. The status and trend of the twenty-four species captured in the present study is given in Table 28. The table indicates that 10 species are abundant. Of these 10, 3 are increasing, 7 are stable, and none are decreasing. Ten species are common; of these none are increasing, 4 are stable, and 6 are decreasing. Four uncommon species were captured, two are stable and two are decreasing. One rare species, the Northern pike was captured, it is decreasing.

A total of 75 species have been reported for Sandusky Bay (Willis, 1974). The 75 reported species are given in Table 29. They are listed according to their abundance. The population trend, where known, is given. The table is based on a search of the records of the Ohio State University Museum of Zoology and an examination of Trautman's Fishes of Ohio

(1957) distribution maps by Charles F. Willis. The table was updated for this study incorporating the 1972-1974 catch records. According to Trautman (1975) eight species have been virtually extirpated from Sandusky Bay. These are: Sturgeon, Muskellunge, Lake chubsucker, Blackchin shiner, Blacknose shiner, Channel darter, Iowa darter, and Longear sunfish.

The reasons for the decline of the Muskellunge have already been discussed. The Sturgeon declined for similar reasons. The building of mill dams in the 1800's and, on the Sandusky River, the Ballville Dam in the early 1900's blocked the Sturgeon spawning runs. The Sturgeon was also a nuisance to the commercial fisherman. They became tangled in the nets thrashing and tearing the nets. For this reason the Sturgeon was often destroyed. The Sturgeon does not reproduce until it is about 20 years old, once the population was down there was little chance of restoring it for a long period of time.

Six of the remaining seven species appear to have been extirpated by similar causes. These six are all reported to be intolerant of turbidity and/or require aquatic vegetation (Trautman, 1957). The Channel darter is the exception to this statement and the reason for its decline is unknown.

Ecosystem A

TABLE 28. STATUS AND TREND OF SANDUSKY BAY FISH

SCIENTIFIC NAME	COMMON NAME	STATUS	TREND	FRY
Lepisosteidae				
Lepisosteus osseus	Longnose gar	Common	Decreasing	
Amiidae				
Amia calva	Bowfin	Uncommon	Decreasing	
Clupeidae				
Alosa pseudoharengus	Alewife	Common		
Dorosoma cepedianum	Gizzard shad	Abundant	Increasing	X
Esocidae				
Esox lucuis	Northern pike	Rare		
Cyprinidae				
Carassius auratus	Goldfish	Abundant		X
Cyprinus carpio	Carp	Abundant		
Notropis atherinoides	Emerald shiner	Abundant		X
Notropis hudsonius	Spottail shiner	Abundant		
Catostomidae				
Carpiodes cyprinus	Quillback	Uncommon	Decreasing	
Catostomus commersoni	White sucker	Common		
Moxostoma	Redhorse	Common		
Ictaluridae				
Ictalurus nebulosus	Brown bullhead	Common	Decreasing	
Ictalurus melas	Black bullhead	Common		
Ictalurus punctatus	Channel catfish	Abundant		
Percopsidae				
Percopsis omiscomaycus	Trout-perch	Common	Decreasing	
Percichthyidae				
Morone chrysops	White bass	Abundant	Increasing	X
Centrarchidae				
Micropterus dolomieui	Smallmouth bass	Uncommon		X
Micropterus salmoides	Largemouth bass	Common		
Pomoxis annularis	White crappie	Abundant		
Pomoxis nigromaculatus	Black crappie	Common	Decreasing	
Percidae				
Perca flavescens	Yellow perch	Abundant		X
Stizostedion v. vitreum	Walleye	Uncommon		
Sciaenidae	Fresh			
Aplodinotus grunniens	Freshwater drum	Abundant		X

TABLE 29. COMPOSITE LIST OF SPECIES PRESENT IN SANDUSKY BAY

		POPULATION TREND
ABUNDANT		
Gizzard shad	*Dorosoma cepedianum*	Increasing
Goldfish	*Carassius auratus*	
Carp	*Cyprinus carpio*	
Emerald shiner	*Notropis atherinoides*	
Spottail shiner	*Notropis hudsonius*	Increasing
Spotfin shiner	*Notropis spilopterus*	Increasing
Bluntnose minnow	*Pimephales notatus*	
Channel catfish	*Ictalurus punctatus*	
White bass	*Morone chrysops*	Increasing
White crappie	*Pomoxis annularis*	
Yellow perch	*Perca flavescens*	
Freshwater drum	*Aplodinotus grunniens*	
COMMON		
Longnose gar	*Lepisosteus osseus*	Decreasing
Alewife	*Alsoa pseudoharengus*	
Rainbow smelt	*Osmerus mordax*	Decreasing
Golden shiner	*Notemigonus crysoleucas*	Decreasing
Mimic shiner	*Notropis volucellus*	Decreasing
White sucker	*Catostomus commersoni*	
Shorthead redhorse	*Moxostoma macrolepidotum*	Decreasing
Black bullhead	*Ictalurus melas*	
Yellow bullhead	*Ictalurus natalis*	Decreasing
Brown bullhead	*Ictalurus nebulosus*	
Stonecat	*Noturus flavus*	Decreasing
Trout-perch	*Percopsis omiscomaycus*	Decreasing
Brook silverside	*Labidesthes sicculus*	Decreasing
Rock bass	*Ambloplites rupestris*	
Green sunfish	*Lepomis cyanellus*	
Pumpkinseed	*Lepomis gibbosus*	
Orangespotted sunfish	*Lepomis humilis*	Increasing
Bluegill	*Lepomis macrochirus*	
Largemouth bass	*Micropterus salmoides*	
Black crappie	*Pomoxis nigromaculatus*	Decreasing
Logperch	*Percina caprodes*	Decreasing
UNCOMMON		
Sea lamprey	*Petromyzon marinus*	
Bowfin	*Amia calva*	Decreasing
Coho salmon	*Onchorhynchus kisutch*	
Chinook salmon	*Onchorhynchus tshawytsha*	
Central mudminnow	*Umbra limi*	Decreasing
Grass pickerel	*Esox americanus vermiculatus*	Decreasing
Stoneroller	*Campostoma anomalum*	

TABLE 29 Continued

		POPULATION TREND
UNCOMMON		
Common shiner	*Notropis cornutus*	
Sand shiner	*Notropis stramineus*	
Fathead minnow	*Pimephales promelas*	Increasing
Quillback	*Carpiodes cyprinus*	Decreasing
Northern hog sucker	*Hypentelium nigricans*	
Bigmouth buffalo	*Ictiobus cyprinellus*	Decreasing
Spotted sucker	*Minytrema melanops*	Decreasing
Golden redhorse	*Moxostoma erythrurum*	Decreasing
Tadpole madtom	*Noturus gyrinus*	Decreasing
Brindled madtom	*Noturus miurus*	Decreasing
Banded killifish	*Fundulus diaphanus*	Decreasing
Smallmouth bass	*Micropterus dolomieui*	
Greenside darter	*Etheostoma blennioides*	
Johnny darter	*Etheostoma nigrum*	Decreasing
Walleye	*Stizostedion v. vitreum*	Increasing
RARE		
Silver lamprey	*Ichthyomyzon unicuspis*	Decreasing
Lake sturgeon	*Acipenser fulvescens*	Decreasing
Spotted gar	*Lepisosteus oculatus*	Decreasing
Mooneye	*Hiodon tergisus*	Decreasing
Lake whitefish	*Coregonus clupeaformis*	Decreasing
Northern pike	*Esox lucius*	Decreasing
Muskellunge	*Esox masquinongy*	Decreasing
Silver chub	*Hybopsis storeriana*	Decreasing
Blackchin shiner	*Notropis heterodon*	Decreasing
Blacknose shiner	*Notropis heterolepis*	Decreasing
Lake chubsucker	*Erimyzon sucetta*	Decreasing
Silver redhorse	*Moxostoma anisurum*	Decreasing
Burbot	*Lota lota*	
Longear sunfish	*Lepomis megalotis*	
Warmouth sunfish	*Lepomis gulosus*	
Iowa darter	*Etheostoma exile*	Decreasing
Channel darter	*Percina copelandi*	
Blackside darter	*Percina maculata*	
Sauger	*Stizostedion canadense*	Decreasing
Blue walleye	*Stizostedion vitreum glaucum*	Decreasing

ECOSYSTEM ANALYSIS

Trophic Dynamics

The Sandusky Bay ecosystem consists of complex interrelationships between the abiotic and biotic components.

Abiotic components play a critical role in the initial link of the food chain; they determine the primary productivity of the system. Radiant energy temperature, mean depth, transparency, currents and substrate are the most important physical factors. Temperature is important in determining metabolic rates. Temperature during spawning and incubation periods of fish, especially Walleye and Yellow perch, are very important in determing year-class success (Hartman, 1973). Reproduction in many species of zooplankton is controlled by temperature (Pennak, 1953).

Mean depth as an indicator of productivity was discussed by Rawson (1953). Rawson compared populations of phytoplankton, benthic organisms, and fish to the mean depth of various lakes. A correlation between production at the various trophic levels and the mean depth was indicated. Rawson found lakes with low mean depths to be more productive. Rawson emphasized that primary production is not as good an indicator of productivity as fish commercial catch records. Fish production is an indicator of the utilization of the lower trophic level production. Sandusky Bay is a shallow body of water with a mean depth of 1.61 meters. Its productivity is thus influenced and enhanced by this abiotic factor.

Transparency and turbidity are two closely related abiotic factors. The amount of light which can penetrate to a given depth, sufficient for photosynthesis, is determined by the turbidity of the water. Turbidity, caused by suspended particles, refracts light, decreasing the depth of the photosynthetic zone. The energy and [illegible] the photosynthetic zone. The highly erodable glacial till bluffs of Sandusky Bay, plus the silt load of the Sandusky River make this an important factor.

Currents in Sandusky Bay are not swift. There is a slow flow from the mouth of the Sandusky River to the lakes. This slow current carries nutrients from the Sandusky River watershed as it flows to the lake making the nutrients available to the producers. Silica is a particularly good example of this process. Silica enters the bay at a 2.5 ppm of 2.5ppm mean value. It enters the lake with a mean value of 0.5ppm. Values decrease as the water flows toward the lake. This indicates utilization by the producers. Further indication of this utilization is that the bottom values tend to be higher than the surface values, not significantly so at the 95% confidence level, but fairly constantly, indicating utilization in the upper photosynthetic zone.

Vertical movement of Sandusky Bay is in harmony with Lake Erie. Long term changes are a result of long term changes in Lake Erie. Short term changes are also often caused by Lake Erie. A seiche in Lake Erie will produce a seiche of smaller magnitude after a time lapse, in Sandusky Bay. These seiches raise and lower the bay level causing oscillation of the water. The water movement may cause damage to producers and consumers alike living in the bay. Turbidity may increase as a result of the water movement. Seiches can also originate in the bay causing similar damage.

Long term changes in water level alter available habitats. Higher aquatic plant habitats can be increased or decreased by the change. Species may simply change to fit the new water level. In either case a change in higher aquatic plants causes a change in the periphyton communities which depend on the plants for their habitat. The higher water levels also increase erosion, causing increased turbidity.

The substrate determines what type of benthic organisms will inhabit the area, and which species of fish will spawn there. Sandusky Bay's soft mud bottom and sparse sand favor Oligochaetes over the Diptera in the benthic community. Only fish tolerant of the mud and silt bottom spawn in Sandusky Bay.

Favorable physical factors combined with sufficient quantities of chemical substances maintains productivity in the ecosystem. Important abiotic chemical parameters are: dissolved oxygen, pH, alkalinity, silica, nitrate nitrogen, orthophosphate and trace elements. These factors also influence other levels of the food chain, especially dissolved oxygen and pH. Dissolved oxygen is necessary in at least 4 ppm for fish life (McKee and Wolf, 1967). Pennak (1946) states that pH is a convienent measurement of complex factors and in itself is of little importance in aquatic communities.

Orthophosphate, nitrate nitrogen, silica, a carbon source (often measured as alkalinity) and trance elements are all necessary to the producers. Sandusky Bay has been shown to have large amounts of orthophosphate, nitrate nitrogen, and silica. The carbon source as indicated by alkalinity is also abundant. Trace elements are probably the limiting factor in this system.

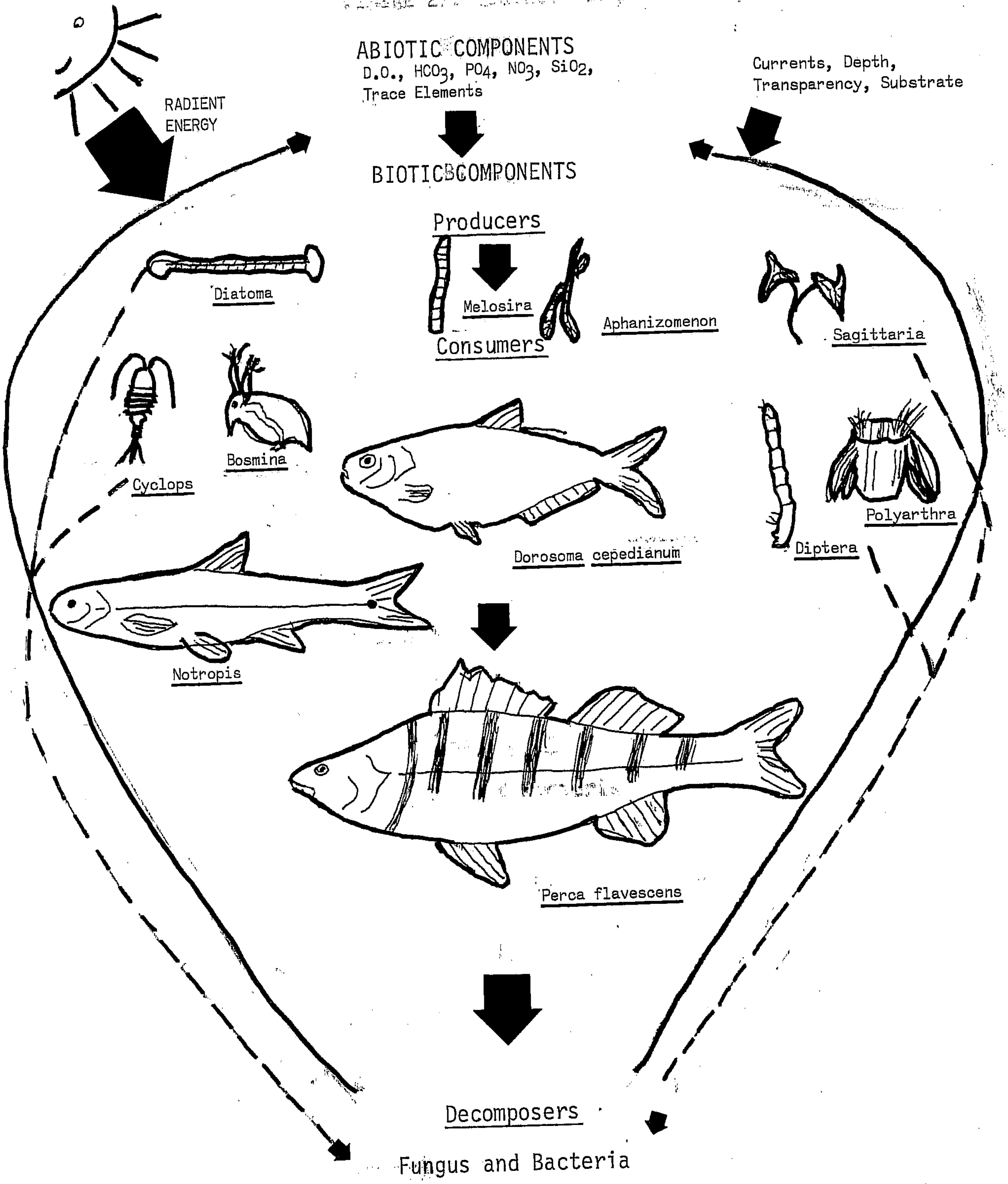
The producers of Sandusky Bay are the phytoplankton and higher aquatic plants. The higher aquatic plants do not have a large role to play as they are only located in isolated areas of the bay. The phytoplankton is the important group of producers. Among the phytoplankton, diatoms are the most abundant, primarily *Melosira, Asterionella formosa, Diatoma tenue elongatum* and *Skeletoneuma subsalsum*. One blue-green algae was abundant *Aphanizomenon flos-aquae*. These plankters provide the base for the next trophic level, the consumers.

The consumers can be on any number of levels, the first level is herbiverous. Herbivores graze on the plankton population or feed on detritus. Among the organisms on this level are the zooplankters. Pennak (1946) stated that zooplankters feed on detritus as much as on algae. The major benthic organisms are omnivores. Diptera feed on microorganisms and detritus. Oligochaetes turn over the bottom mud much as do terrestrial earthworms. Other herbivores are the Goldfish, Carp, and Gizzard shad. Tiffany (1921) described the Gizzard shad as " the most wonderful combination of tow net and centrifuge...." The Gizzard shad forms a part of the base for the next trophic level, the carnivores. The Walleye and White bass were the major carnivores in Sandusky Bay with the Walleye in all probability acting as the top carnivore.

Organic and inorganic sediments entering the bay from the river or by the death of an organism are transformed into inorganic compounds and cycled back into the system at the producer level. The species of decomposers present in Sandusky Bay were not determined in this study.

Figure 27 illustrates the relationships of the producers, consumers, and decomposers. It is a cyclic process with the nutrients being circulated through the system. The system is powered by light energy, drawing on the environment for raw materials. The producer level begins

FIGURE 27. ENERGY FLOW IN SANDUSKY BAY ECOSYSTEM



the cycle, the consumer level continues the cycle, containing many steps within the level. Ultimately death occurs, returning the organisms to the bottom where they are decomposed and the raw materials for the continuation of the cycle are released.

Sandusky Bay-Lake Erie

Sandusky Bay is an estuary of Lake Erie, interacting with and influenced by its waters. The geology, climate, and geography are similar. The morphometry of the two basins is quite different. Lake Erie has an area of 25,690 sq. km. and a mean depth of 18.5m (Hartman, 1973). Compared to Sandusky Bay with an area of 162 sq. km. and a mean depth of 1.61m., there is a considerable difference. The bay's water level is controlled by Lake Erie, both in short term fluctuations and long term changes. As previously discussed seiches originating in Lake Erie are transmitted to Sandusky Bay. There is a time lapse and a decreased amplitude caused by the constricted channel connecting the two bodies of water. Sandusky Bay also changes to reflect the long term water level changes of the lake. It maintains the same level as Lake Erie.

The physical factors are different in some parameters and similar in others. Transparency is markedly improved in Lake Erie over Sandusky Bay. Lake Erie transparency readings for 1973 ranged from 1-9m (CLEAR, 1973). Sandusky Bay's highest transparency reading was 0.60m. It is felt that this difference is due to the high silt load carried by the Sandusky River to Sandusky Bay. Much of this fine silt is carried through the bay to Lake Erie, causing low transparency readings in the bay.

Conductivity is approximately twice as high in Sandusky Bay as in Lake Erie. Station means for Sandusky Bay ranged from 350-600 micromhos/centimenter. Lake Erie values for 1973 ranged from 220-320 micromhos/centimeter (CLEAR, 1973). Sandusky Bay is fedd by highly mineralized ground water. Artesian wells on adjacent land measured conductivity in the thousands of units.

Values for pH did not differ greatly between Lake Erie and Sandusky Bay. Lake Erie pH is a little higher and has a broader range: 8.4-9.4 (CLEAR, 1973) as compared to station means of 7.9-8.1 in Sandusky Bay.

Alkalinity parallels conductivity. Lake Erie ranged from 82-106 ppm while Sandusky Bay ranged from 111-165 ppm for station means.

Dissolved oxygen comparisons indicate Lake Erie is highly variable ranging from anoxic in places and at certain times to saturation in other places and different times. During the present study Sandusky Bay values did not fall below 5.6 ppm and maintained station means of 10-11 ppm.

Benthic populations appeared to be qualitatively similar but quantitatively different. Oligochaetes and Diptera were dominant forms in both instances. Sphaeriidae were also a major group in Lake Erie. Sandusky Bay mean value for benthic organisms in 1973 was 1,546 organisms per sq square meter. Lake Erie, in 1973, had a value of 3,800 organisms per square meter (CLEAR, 1973). The lake appears to contain a larger benthic population. No recent numbers for plankton were available for comparison in Lake Erie, but Reitz (1973) reported diatoms to be the major group in Lake Erie. Sandusky Bay phytoplankton was also dominated by diatoms. Zooplankton figures or abundance were not available for recent years.

[illegible]

W

Fish production in Sandusky Bay is much higher than Lake Erie. Sandusky Bay produced 28% of the total commercial catch for the Ohio waters of Lake Erie in 1973 and 1974. Yet Sandusky Bay contains only 2% of the area. Sandusky Bay is also considered to be an important spawning ground and an equally important nursery area (Hartman, 1973).

Sandusky Bay-Future Predictions

The future of Sandusky Bay hinges on the future of its watershed. The watershed is presently extensively utilized for agriculture, with little emphasis on conservation. If this use continues with the present practices and attitudes unchanged, Sandusky Bay has only one path open—further degradation. The best that can be expected is to maintain the status quo. The source of the degradation is and will continue to be the runoff from the agricultural watershed. The Sandusky River carries a heavy silt load which enters Sandusky Bay making its waters turbid, eliminating higher aquatic plants and decreasing habitat and spawning sites for Sandusky Bay fish species. If the status quo is maintained the degradation of Sandusky Bay will continue. An increase in turbidity might have an impact in several areas: 1) photosynthetic zone could be reduced, decreasing the phytoplankton population; 2) White bass, White crappie and Walleye populations might decrease, while the Gizzard shad would continue its dominance.

A change in agricultural practices to decrease the silt load would have an interesting and unpredictable impact. One might hypothesize the following changes would occur: 1) the photosynthetic zone would increase, plankton might increase unless limited by trace minerals or nutrients; 2) higher aquatic plants might return in their former numbers;

3) spawning success might increase: 4) species currently not abundant but formerly present in Sandusky Bay might return.

The future of Sandusky Bay is an unknown variable in a complex equation of the Great Lakes watershed management.

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