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Some Limnological Conditions Relative to Winter Kill of Fish in Ice-Covered Representative Farm Ponds in Eastern South Dakota

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SOME LIMNOLOGICAL CONDITIONS RELATIVE TO WINTER KILL
OF FISH IN ICE-COVERED REPRESENTATIVE FARM
PONDS IN EASTERN SOUTH DAKOTA

BY

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SOME LIMNOLOGICAL CONDITIONS RELATIVE TO WINTER KILL

OF FISH IN ICE-COVERED REPRESENTATIVE FARM

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

An aquatic environment involves many complex relationships biologically, physically and chemically. Many of these relationships are difficult to measure or are little understood.

In nature, aquatic environments accommodate many types of aquatic life. Ecological disturbances may cause the environment to become unfit for economically important forms of life. Human interference often causes polluted waters and naturally occurring disturbances are common. A distrubance of this kind is one of the major problems of fisheries management in the northern Great Plains area -- seasonal anaerobosis of fish or other aquatic animals and plants, commonly known as winter kill. Winter kill is usually a result of dissolved oxygen depletion in the water, although under certain conditions lethal agents may cause death.

The basic causes involved in winter kill are known, but many limnological relationships remain unsolved. There have been very few studies on winter conditions of lakes in relation to winter kill. Due to the many questionable or unknown factors relating to winter kill and the major problem in fisheries management it creates, this study was undertaken to gain a better understanding of the winter-kill phenomenon.

This study, which was initiated on September ~~25, 1959~~ 30 1972 and concluded on April ~~26, 1960,~~ 21 1973 was conducted on ~~two established farm ponds and on~~ a newly constructed dugout pond in eastern South Dakota. The objectives were to determine if the various measurements obtained through methods cited below could be correlated and to determine if they could provide an index for predicting winter kill.

(2)

The greatest problem caused by winter kill is not a total kill of fish, as is commonly thought, but a partial kill of fish life. It is known that some game fishes are more susceptible to winter-kill conditions than many of the rough or non-game fishes, therefore, when partial winter kills occur, a lake may be left with a population of rough fish which may gain control of the lake. Here to

Winter-kill conditions are more likely to develop in fertile, shallow lakes which contain large amounts of dissolved and suspended organic matter in their waters. This organic matter is subject to aerobic decomposition which utilizes large amounts of dissolved oxygen. The deep, clear lakes usually do not contain appreciable amounts of organic matter in their waters; and, therefore, little dissolved oxygen is used by decomposition of organic matter (Eddy and Surber, 1947).

Dissolved oxygen in water is supplied mainly as a by-product of photosynthesis. Green plants combine carbon dioxide and water, utilizing the energy of sunlight to synthesize carbohydrates, giving off oxygen. Another source is direct absorption of the oxygen into the water from the atmosphere. Water can absorb large amounts of oxygen in this way especially when the wind causes agitation that greatly increases the content and mixing of the water and air.

Most of the dissolved oxygen is utilized in the aerobic decomposition of the dissolved or suspended organic matter present in the water. It is commonly believed, by the public in general, that fish or other aquatic organisms use large amounts of dissolved oxygen in respiration. This assumption is not true. Over eight tons of bass (four grams in size) in a one-acre pond three feet deep would utilize only 10 parts per million (p.p.m.) dissolved oxygen in 90 days.

During the time when water is ice-free dissolved oxygen is usually not of great concern. In open water light penetration is usually sufficient to permit photosynthesis. In addition some oxygen will be absorbed from the atmosphere during wind action. Under ice cover, however, the situation changes. The aquatic environment becomes sealed in and oxygen can no longer be absorbed from the atmosphere. The main or only source of oxygen is the green plants which carry on photosynthetic production by action of the light that penetrates the ice and water. Because of this, light penetration often becomes the critical factor in the survival of aquatic life. In those lakes which are clear and deep and have low phytoplankton populations aquatic life must exist on the dissolved oxygen present in the water at the time of freeze up. It can do this because of the low organic demand of these waters. The fertile, shallow lakes which have a high organic demand become dependent upon their phytoplankton populations for oxygen production. If the ice becomes cloudy or snow covered and thereby blocks out the sunlight, photosynthesis will cease. Decomposing suspended or settled remains of plants and animals which flourished during the summer exert a demand on the dissolved oxygen as does the respiration of the plants and animals still existing in the water. In this way, if sunlight is excluded, the water may become completely void of dissolved oxygen. Here

4 The primary method of determining the winter condition of northern ponds or lakes is the dissolved oxygen test. Other methods by which

winter conditions can be determined are the biochemical-oxygen-demand test; measurement of light penetration through snow, ice and water; turbidity measurements; the light-and-dark-bottle test; carbon dioxide measurements; hydrogen sulfide measurements and ammonia concentrations.

The test for dissolved oxygen, commonly referred to as D.O., measures the amount of dissolved oxygen in the water in milligrams of dissolved oxygen per liter of water or parts per million. This test is important because it shows the amount of dissolved oxygen available at any time for respiration of plants, animals and for the oxidation of organic matter.

The biochemical-oxygen-demand test (B.O.D.) measures the quantity of dissolved oxygen in parts per million required during stabilization of the decomposable organic matter by aerobic biochemical action. As this test measures the oxygen demand of substances in the water on dissolved oxygen it can be used as an index of the probability of winter kill of fishes.

By measuring the intensity of light striking the ice surface, the amount of light penetrating the ice, and the depth of light penetration in the water, the zone where sufficient light is available for photosynthesis may be determined. Also from this information the effects of the ice condition, snow cover and turbidity on light penetration may be determined.

Turbidity is directly related to light penetration. Turbidity is a measure of the amount of dissolved and suspended materials present in the water which impede the transmission of light. Turbidity measurements give an indication of the light transmitting qualities of the waters.

The respiration of the ponds can be measured by the light-and-dark-bottle method. This test, which is conducted under water, measures the amount of oxygen produced by photosynthesis and the oxygen consumed by respiration and determines if more oxygen is being produced than is consumed.

REVIEW OF LITERATURE

There have been few complete studies on winter conditions of lakes in relation to winter kill, although certain of the phenomena of lakes under winter conditions have been observed by certain individuals. Only one complete study of this nature is known; this was conducted by John Greenbank (1945) during the winters of 1937-38 through 1942-43 on several lakes in southeastern Michigan.

Dissolved Oxygen

Dissolved oxygen is probably the most important factor in the survival of aquatic life during winter conditions. Both Greenbank (1945) and Scidmore (1957) pointed out that measurements of dissolved oxygen is the best indication of the winter condition of a lake as far as fish are concerned.

The primary source of oxygen in an ice-covered lake is from photosynthetic activity of phytoplankton. Verduin (1956) reported that the mean photosynthetic rate of lake phytoplankton under optimal light (natural conditions) is about 16 micrograms of oxygen produced per microliter of organisms per hour. The results of Bartsch and Allum (1957) in their work on artificial sewage ponds compare favorably to that of Verduin. Wisniewski (1958) measured the oxygen produced by live algae in a closed bottle. He found that in continuous light under experimental conditions more oxygen was produced than was used in B.O.D. reactions.

Greenbank (1945) points out that depletion of dissolved oxygen in lakes due to respiration of fish is not likely. The results of experiments by Clausen (1936) on the consumption of oxygen by freshwater fishes show that fish use only a small proportion of the available dissolved oxygen.

There has been a considerable amount of work done on the toleration threshold of dissolved oxygen for freshwater fishes. Cooper and Washburn (1946) determined the dissolved oxygen thresholds for several species of fish. They stated that their thresholds were lower than those reported by Moore (1942). There has been much variation in the results of tests conducted to determine the dissolved oxygen requirements of fish. Tarzwell (1958) stated that:

> A great many studies have been made of the oxygen requirements of fishes. Investigators have not always used a uniform approach. In fact, there has been great diversity in the species studied, the experimental methods used, the objectives of the study, the caliber of the investigation and the interpretation of results. Consequently, data obtained have varied widely and have not always been in agreement.

He also pointed out that fish can live for a considerable length of time in cold water at low oxygen levels, but their life cycles cannot be completed at these low levels and the objectives should be to maintain higher dissolved oxygen levels.

Biochemical Oxygen Demand

B.O.D. tests are the simplest means by which an indication of the organic demand of a lake may be determined. Greenbank (1945) observed higher B.O.D.'s in surface waters than near the bottom. He stated this may indicate more zooplankton and phytoplankton suspended near the surface and that as they settle they are oxidized before reaching the bottom. He also pointed out that the suspended material in the water was probably responsible to a large degree for oxygen consumption under ice. The investigations of Birge and Juday (1926) have shown that the waters of Lake Mendota and several other lakes contain about an average of 14 or 15 milligrams of organic matter per liter.

Excess vegetation in ponds at times can cause oxygen depletions even in open-water situations. Wiebe (1934) reported that in summer the danger of oxygen depletion exists on warm nights or murky days when in the ponds there becomes an accumulation of dead and decaying vegetation.

The respiration of plants is usually an insignificant factor in the B.O.D. test but occasionally may become noticeable. Olson (1932) observed large amounts of algae producing oxygen during daylight but through their respiration at night cause an oxygen depletion. According to Roach and Wickliff (1934) Buckeye Lake in Ohio became so choked with submerged and surface vegetation in some areas that respiration depleted the dissolved oxygen in those areas to an average of 0.2 p.p.m.

Wisniewski (1958) showed that the oxidation rate of dead algae cells was higher than the oxidation rate during respiration of live cells.

Light Penetration

Light is essential for photosynthesis to take place and as a result the effect of light on the aquatic environment has had much study. The importance of light is indicated by Clarke (1939) who stated that the productivity of any body of water is dependent on the efficiency with which plants can convert solar radiation into organic tissue. Plants are not too efficient in this process thus light is often a controlling factor in the aquatic environment.

As light penetrates water it is reduced in intensity and, according to Clarke (1954), that intensity where the rate of photosynthesis and respiration of the phytoplankton is in balance is termed the "compensation intensity." This is the lower limit of the euphotic zone which is the area where there is sufficient light for photosynthesis. He also pointed out that for phytoplankton the compensation intensity is generally about one percent of the incident light at the surface. The same intensity was indicated by Bartsch and Allum (1957).

Limit-of-visibility tests and light measurements are the two principle means of measuring light penetrations in water. The Secchi disk is used in making the limit-of-visibility test and photronic-cell equipment is used to measure light (Welch, 1948). Welch wrote that the Secchi-disk method gives only an indication to the visibility and does not measure light. It does, however, serve to compare different waters. Verduin (1956) attempted to correlate Secchi-disk readings and the depth of the euphotic zone by making simultaneous readings with the Secchi disk and a photometer. He found that by multipling the Secchi-disk reading in meters by a conversion factor of five, he could approximate the euphotic zone depth in meters. He also reported that other investigators used different conversion factors to get accurate results. When using measurements obtained from paired photometers and a Secchi disk, Beeton (1957) found the Secchi-disk readings to be at an average of 14.7 percent of the surface incident light. He also suggested more intensive study to determine if Secchi-disk readings can be correlated with light penetration measurements.

Light intensity measurements at various depths are usually made to determine light penetration. Greenbank (1945) pointed out that light penetration measured by photometers composed of photoelectric cells has come into common use. In all studies cited in this paper which involve measurement of light, the measurements were made by means of photoelectric cells, unless otherwise stated.

The amount of light penetrating water, ice and snow depends upon many factors. Greenbank (1945) and Clarke (1954) point out that the quality as well as the quantity of light penetration is an important factor in photosynthesis and that the greatest rate of photosynthesis occurs in the red region of the visible spectrum. Clarke further stated that blue light yields the second highest photosynthetic rate.

The quantity of sunlight available to the aquatic environment varies daily and seasonally. Whitney (1938) demonstrated the daily variation of solar radiation by measurements with a thermopile and photocells. He found the maximum radiation at noon and the minimum in early morning and late afternoon; transmissions on clear and cloudy days were about the same. Seasonal variation was also reported by Verduin (1956). His study of Lake Erie showed that highest photosynthetic activity occurred in June, and that it was correlated with the solar radiation curve. According to Oswald and Gotaas (1955), astronomical, geographical, and meteorological conditions influence the amount of solar energy which is incident upon the earth's surface. They compiled a table from which the monthly values of total and visible wave lengths of the spectrum can be predicted by north latitudes for indicated segments of the earth. They also devised a graph from which the mean percent of total time the sun is above the horizon can be determined.

The absorption of light by water can have a great effect on the availability of light to the aquatic environment. Clarke (1939) reported that as sunlight comes in contact with the surface of the water the various components of the spectrum are in unequal quantities and that these are absorbed at different rates as the light penetrates the water. He also related that even in distilled water certain parts of the spectrum are quickly absorbed. Natural waters differ from distilled water in that they contain materials which inhibit the transmission of light. James and Birge (1938) classified the various substances in lake water as either suspensoids or colors. Suspensoids consist of organic or colloidal materials which will settle out or which can be filtered. Colors are the result of decomposition of organic matter in the lake water.

The penetration of light through snow and ice cover is a very important factor in the northern regions where lakes are ice-covered for considerable periods of time. Despite the importance of ice cover, few studies have been made under these conditions.

Croxton, Thurman and Shiffer (1937) conducted experiments on the transmission of light through snow and ice. They found that 14 inches of clear ice transmitted sufficient light for photosynthesis. The addition of snow, however, greatly reduced light penetration and eight inches of snow almost completely eliminated light penetration. They also indicated that dirt, soot, granular condition and wetness of the snow helped reduce the transmission of light. The conditions of their experiments were artificially created. Chandler (1942) found on western Lake Erie that only 58 percent of the incident light penetrated ice 40 centimeters thick which was equivalent to 40 centimeters of water with 20 p.p.m. turbidity. Greenbank (1945) in his investigations discovered that the transmission of light through ice varied with the condition of the ice and that his measurements compared favorably with those of previous investigators. His studies reveal that the transmission of light through ice is probably sufficient unless the ice is exceptionally cloudy or opaque. He noted that with snow cover light is reduced considerably. The transmission varied from 28 percent for one inch of slushy snow to 0.7 percent for 10 inches of dry snow. In general, he concluded that less light will penetrate wet snow than dry snow.

Greenbank likewise stated that snow has a very high surface reflection compared to water or ice. This explains in part the light blocking of snow.

Greenbank's investigation exhibited a definite correlation between snow depth and dissolved oxygen concentrations. In their complementary study Cooper and Washburn (1946) observed oxygen depletion in some Michigan lakes when there was a prolonged snow cover.

Turbidity

Turbidity is an expression of the optical quality of water and is caused by suspended matter, such as clay, silt, finely divided organic matter, plankton and other microscopic organisms (American Public Health

Association, 1955). It is therefore directly related to light penetration in water as previously reviewed.

Any study of light penetration involves turbidity. James and Birge (1938) state that those substances contained in lake waters which effect the transmission of light cause turbidity. Chandler (1942) studied light penetration and its relation to turbidity in western Lake Erie. He indicated the quality of the suspended material affected the light which was available to aquatic organisms.

The differential absorption of various parts of the spectrum in natural waters was attributed to the suspended and dissolved materials in the waters, according to Clarke (1939).

Turbidity is also related to the organic matter present in the aquatic environment. Ellis (1936) observed that erosion silt causing turbidity carried with it organic matter which created an oxygen demand in the surrounding water. Oxygen depletion caused by deposition of silt and detritus was observed by Ellis (1940) in the upper basin of Elephant Butte reservoir, New Mexico. He determined silt conditions by turbidity measurements.

Light-and-Dark-Bottle Tests

Light-and-dark-bottle tests provide a means by which the respiration of a pond can be measured. Ryther (1956) discusses the use of the light-and-dark-bottle test to measure gross oxygen production in the measurement of primary production. He points out that the dissolved oxygen in the light bottle is influenced by respiration of plants and bacteria, therefore, the dark bottle is used to correct for respiration.

Gribbins (1959) indicated the value of light-and-dark bottle tests for classroom demonstrations on the measurement of dissolved oxygen in photosynthesis and respiration. According to Ryther (1956), light-and-dark bottle tests should not exceed 48 hours as photosynthesis occurs at a constant rate from 24 hours to 48 hours, then decreases. He suggests the tests should not exceed the daylight portion of one day.

Other Factors

Under oxygen depletion conditions various forms of anaerobic bacteria produce several gases during the process of decomposition of organic matter. Most of these gases are toxic to fish and to other aquatic organisms. In general they affect the respiration of fish by reducing the ability of the hemoglobin of the blood to unite with oxygen or to liberate carbon dioxide. Some of these gases are carbon dioxide, ammonia and hydrogen sulfide. Greenbank (1945) noticed production of hydrogen sulfide several times during his investigations, although he seldom noticed any appreciable quantities of free carbon dioxide. He concluded that oxygen depletion was the main cause of winter kill but that high concentrations of the other gases are contributing factors.

In a study to determine the effect of pulp mill wastes on stream pollution, Van Horn, Anderson and Katz (1949) found that 1 p.p.m. of hydrogen sulfide was the minimum lethal dose to small cyprinidae. If 2.5 p.p.m. or more of ammonia are present in the water harmful effects may be expected according to Ellis, Westphal and Ellis (1948) but they further stated that some fishes can tolerate from 3 to 10 p.p.m. Brockway (1950) found harmful concentrations of ammonia to be much lower than this. His study indicated that if over 0.3 p.p.m. ammonia is present in the water the metabolism of the fish is endangered and at 1 p.p.m. the oxygen concentration of the blood is decreased about 1/7 of its normal value and carbon dioxide content of the blood increases about 15 percent. Lagler (1956) pointed out that free carbon dioxide in excess of 20 p.p.m. is harmful to fish. More recently Scidmore (1957) conducted an investigation of carbon dioxide, ammonia and hydrogen sulfide as factors contributing to fish kills in ice-covered lakes. His concluding statement was that winter kills are usually related to concentrations of these gases as concurrent phenomena rather than as the cause and effect.

TECHNIQUES OF THE STUDY

The study was initiated on September 25, 1959. Until the ponds became ice-covered all samples were taken from a boat. After ice cover, holes were drilled and samples were taken through the ice.

Each time the limnological measurements were made weather data was recorded. This included sky conditions, wind velocity, air temperature and other pertinent conditions. The time of arrival at and departure from the pond was recorded.

Water temperature was measured with a Taylor maximum-minimum thermometer. The surface temperature was taken before the bottom temperature. During ice cover, surface temperatures were measured just below the ice. Bottom temperatures were measured about 30.4 cm. from the bottom to prevent any agitation of bottom material.

Water samples were collected in the same area and depth where the temperatures were measured. The samples were taken at approximately the same location in each pond throughout the study. All water samples collected in the study were taken with a Kemmerer (1200 milliliter) water sampler. With this device samples can be taken from a known depth and brought to the surface in an apparently unmodified condition (Welch, 1948).

The first water samples on any given date were always taken from the surface. This included water for the D.O. and B.O.D. tests, and for the preserved sample. The water used in the D.O. test was carefully introduced into a standard biochemical-oxygen-demand bottle to prevent agitation or bubbling and was then treated chemically. The surface

B.O.D. and preserved samples were then taken. The bottom samples were collected by the same procedure. The surface and bottom B.O.D. and preserved samples were placed in clean one-half gallon wide-mouthed jars. About five milliliters of chloroform was used as the preservative in the preserved samples.

Immediately after the dissolved oxygen sample was collected the test was initiated and brought to a stable condition in the field by a standard procedure. The final titration was done in the laboratory. All D.O. tests in this study were by the sodium-azide modification of the Winkler method (American Public Health Association, 1955).

When the ponds became ice-covered, light penetration measurements were taken with matched surface and submerged photronic cells (Weston, Model 865 RR) sensitive in a range from 420-720 millimicrons (Figure 1). The surface well was equipped with a Kodak Wratten neutral-density filter of 25 percent transmission. Readings were made on a microammeter which was connected through a series of eight graded resistors to the cells. Under intense light conditions additional resistance could thus be added to keep all readings within the limits of the microammeter.

Light penetration was measured under clear ice and under ice with snow cover. If a pond was completely snow covered a small area was cleared then a clear ice reading was made in addition to that under snow cover. At the time the light measurements were taken, sky condition and time of day were recorded. The surface cell was set on the ice surface fully exposed to the sun. The submerged cell was then placed with the face of the cell flush with the under surface of the ice. Surface cell

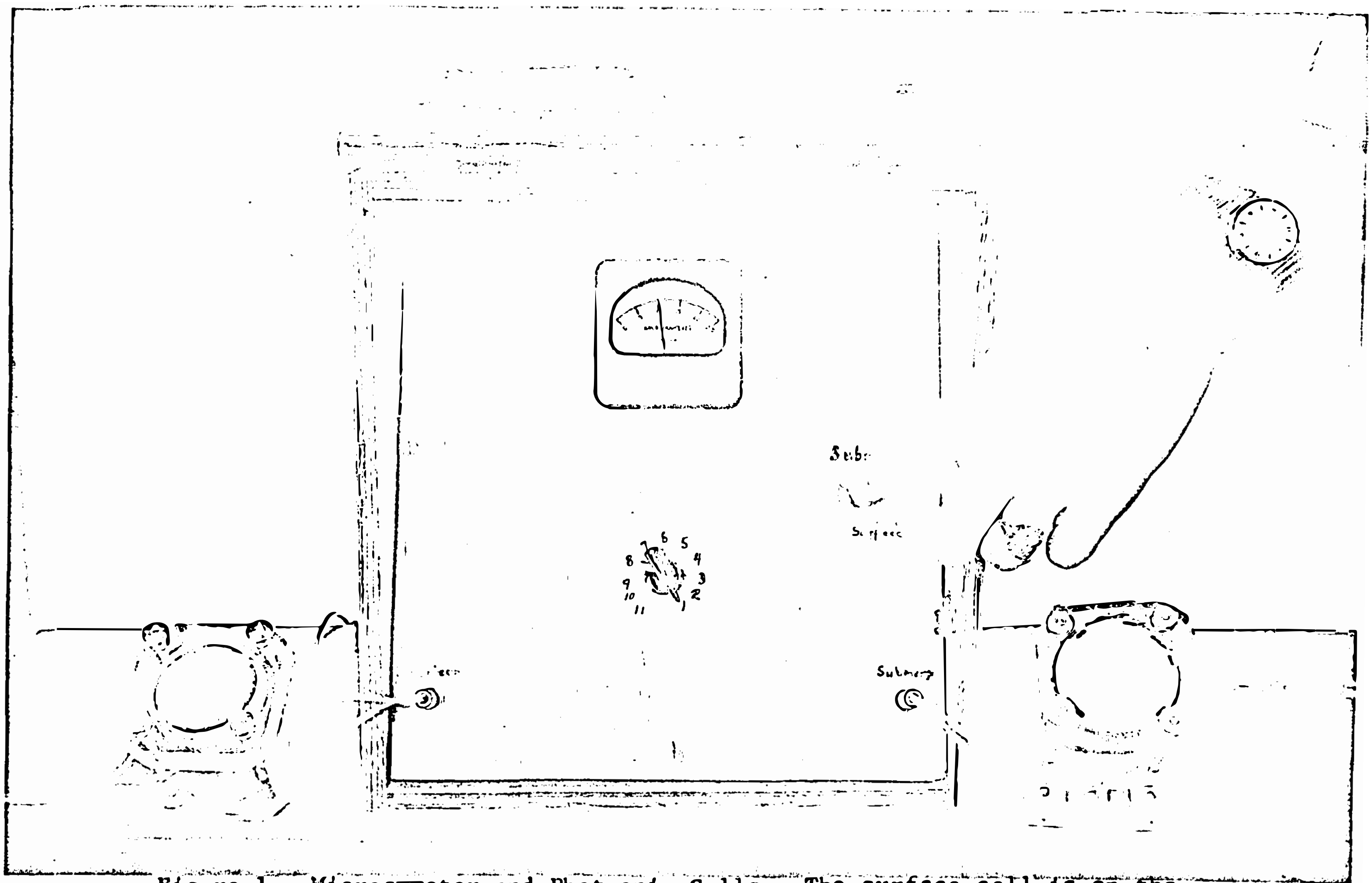

Figure 1. Microammeter and Photronic Cells. The surface cell is on the left and the submerged cell is on the right. The microammeter shows the reading of the submerged cell.

and submerged cell readings were made within 10 seconds of each other. These alternating readings were continued and the submerged cell was lowered until it reached the depth at which one percent transmission of the surface light was determined. The depth of the submerged cell was controlled by a calibrated pole. A hinged two foot extension was attached to the lower end of the pole. The hinged portion could be brought to a horizontal position by pulling a cord attached to it or be left extended (Figure 2).

In the laboratory the B.O.D. samples were warmed to about 25-30 degrees Centigrade and agitated frequently to release the excess dissolved oxygen. Had this not been done, the samples when placed in the 20 degree Centigrade incubator might have been supersaturated for that temperature, resulting in a loss of oxygen not attributable to the stabilization of organic material. B.O.D. tests were then set up by diluting the water samples collected from the ponds with standard dilution water. The percent dilutions used varied depending upon which pond the sample was from but the dilutions used were those estimated to yield percent depletions in the significant range of 40-70 percent as determined by experience with the B.O.D. technique. The standard dilution water consisted of deionized and charcoal filtered water (American Public Health Association, 1955).

For those B.O.D. tests set up as 100 percent pond water, the sample was left in the collecting jar. It was mixed thoroughly and enough siphoned out to fill two Standard B.O.D. bottles. One of these was placed in a standard B.O.D. incubator and the initial D.O. was

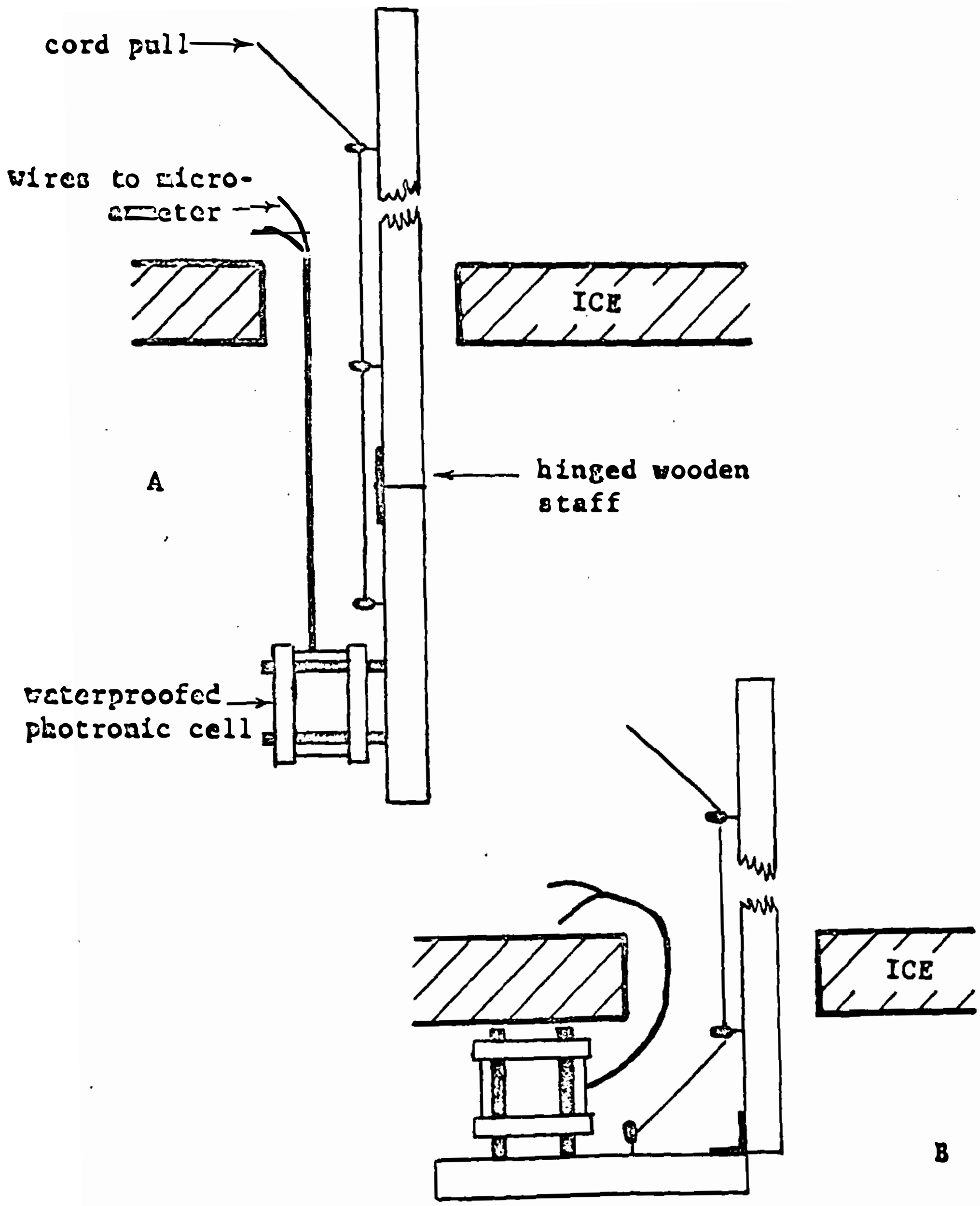

Figure 2. Apparatus Used for Measuring Light Penetration Under Ice. A. Cell being lowered into submerged position. B. Cell in submerged position for reading.

determined from the other.

The samples which required dilution were mixed in the collection jar and the desired amount measured into a 1000 milliliter graduated cylinder. For example, frequently dilutions of 50 percent and 25 percent were used. The graduated cylinder was filled to the 500 milliliter mark with pond water and 500 milliliters of standard dilution water were added, making a 50 percent dilution. This dilution was mixed with a stirring rod and then two standard B.O.D. bottles were filled using a siphon. The first bottle was placed in the standard B.O.D. incubator and the second was used as a check. The dilution in the graduated cylinder was then wasted to the 350 milliliter mark and refilled with standard dilution water to the 700 milliliter mark making a 25 percent dilution. The mixing and siphoning procedures were then repeated. The siphoning procedures were executed with the utmost care to prevent any agitation or bubbling of the water samples. All samples were incubated for five days at 20 degrees Centigrade in the standard B.O.D. incubator. A sample of the standard dilution water was also incubated to determine if it had any B.O.D. After incubation, D.O. tests were made on the samples. The final dissolved oxygen reading was substracted from the initial reading. The difference obtained was the oxygen used during incubation. The final B.O.D. was then determined by correcting this difference to the dilution factor.

Turbidity measurements were made on the preserved water samples. Preservation of water samples was not necessary for turbidity measurements, but the preserved samples taken in this study were also used for other tests not of concern in this problem. Only small portions were used for turbidity measurements.

Turbidity is measured in turbidity units, (parts per million), as produced by 1 p.p.m. of silica in distilled water (Welch, 1948). The standard method for measuring turbidity is the Jackson candle method and any other instruments used should be calibrated against it (American Public Health Association, 1955). Turbidity measurements in this study were made with a Bausch and Lomb Spectronic-20 spectrophotometer which was calibrated against the Jackson candle method.

Toward the latter part of the study the respiration of the ponds was measured. A water sample was taken from the depth at which one percent of the incident light penetrated and three standard B.O.D. bottles were filled. An initial D.O. test was run on water in one bottle. Of the remaining two bottles, one was wrapped in aluminum foil to exclude all light and then both were placed in a hardware cloth basket and lowered to the same depth from which the samples were taken. The baskets were left under water for a 48 hour period, retrieved, and D.O. tests were run on the light and dark bottles. By comparing the results of the D.O. tests on the light and dark bottles with that of the initial values, the oxygen produced or consumed in each bottle could be determined. The significance of this test is the oxygen produced by photosynthesis in excess of that consumed by respiration in the light bottle versus oxygen consumption by total respiration in the dark bottle. In optimum conditions the net production of oxygen is greater than that consumed by total respiration.

On several occasions tests for carbon dioxide, hydrogen sulfide and ammonia were determined on pond waters. The carbon dioxide and hydrogen sulfide tests were made in the field and the test for ammonia was conducted in the laboratory.

Carbon dioxide was determined by the sodium hydroxide titration method with phenolphthalein as the indicator (Welch, 1948).

Hydrogen sulfide was measured with a Hach hydrogen sulfide kit. This method involves aerating the hydrogen sulfide out of the water by addition of an effervescent tablet. The gas passes through lead acetate paper turning it a brown color if hydrogen sulfide is present. The amount of hydrogen sulfide in the water is determined by comparing the color of the lead acetate paper to the color chart in the kit.

Ammonia was determined by direct Nesslerization (American Public Health Association, 1955). The final measurement of ammonia in parts per million was made by color comparison on the spectrophotometer.

STUDY AREAS

The study areas consisted of two established farm ponds - Christie Pond and McNeil Pond - and one newly constructed dugout pond, Ullman Dugout. These areas were chosen because of accessibility in most kinds of weather and because they are representative of many of the farm ponds in eastern South Dakota. Ullman Dugout was chosen to serve as a check for the other two areas. Because of its recent construction, it would provide water which was low in organic matter, therefore less likely to winter kill.

Christie Pond is located in the southeast 1/4, Section 11, Township 112 North, Range 50 West, Brookings County, South Dakota. The land is owned and farmed by Philip Christie. The pond was formed by an earthen dam constructed in 1955. The pond contains approximately three acre-feet of water and has a maximum depth of about 2.1 meters (m.). The pond is supplied by drainage from the surrounding terrain. The land surrounding the pond is pasture, somewhat overgrazed.

Christie Pond was originally stocked with largemouth bass, (*Micropterus salmoides salmoides*); bluegills, (*Lepomis macrochirus*); and fathead minnows, (*Pimephales promelas promelas*). In the winter of 1957-58 it suffered a winter kill and only fathead minnows survived. In July of 1958 it was again restocked with largemouth bass and bluegills. It then suffered winter kill in 1958-59 and once more only fathead minnows survived. It was not restocked and it is presumed only fathead minnows existed in the pond when this study was initiated.

Ullman Dugout is located in the northeast 1/4, Section 6, Township

111 North, Range 49 West, Brookings County, South Dakota. The dugout is owned by Winston Ullman. It was constructed according to the Soil Conservation Service specifications in the summer of 1959. It has an approximate surface area of 8,056 square feet and a maximum depth of about 3.4 m. The water table in the area is close to the surface so that seepage constitutes the primary water supply of the dugout. There is no drainage into this pond. The dugout is located in a much over-grazed pasture.

In October, 1959, rainbow trout, (Salmo gairdneri), were planted in the dugout. The presence of any other fish species is unlikely.

McNeil Pond is located in the northwest 1/4, Section 34, Township 108 North, Range 48 West, Moody County, South Dakota. The land is owned and farmed by John McNeil. An earthen dam constructed in 1956 forms this pond. The volume of the pond is approximately three acre-feet with a maximum depth of about 3 m. The pond is situated in a natural drainage lane bordered on two sides by small hills covered by a good stand of native grasses, lightly pastured. At the crest of one of these hills there was a silage pit with drainage into the pond.

McNeil Pond was stocked with largemouth bass, bluegills, and yellow perch, (Perca flavescens). Winter kill during 1958 was almost complete and during the study it is doubtful if any fish were present.

RESULTS AND DISCUSSION

Christie Pond

The dissolved oxygen concentrations and B.O.D.'s encountered in Christie Pond during the period of this study are plotted on the graph in Figure 3. From this graph it will be noted the dissolved oxygen values during the initial part of the study were slightly higher than 10 p.p.m. During this period the water was cooling resulting in higher saturation values for dissolved oxygen. Frequent winds which thoroughly mixed the water with the air introduced a considerable amount of dissolved oxygen from the atmosphere. During this period much of the large crop of summer phytoplankton and zooplankton probably died.

In the first week in November the pond became ice covered and remained in this condition until the spring break-up occurred the first week in April.

Dissolved oxygen in the surface water remained above 10 p.p.m. for a short time after the pond became ice-covered, while the dissolved oxygen in the water near the bottom dropped to 6.5 p.p.m. Table I, in which the light penetration measurements through snow, ice and water are compiled, shows that at this time there was sufficient light penetrating the ice to permit photosynthesis in the upper water. Since this was the case, then sufficient oxygen was being produced to satisfy the organic demand of the water. The water near the bottom was well below the euphotic zone, therefore the organic demand began its drain on the dissolved oxygen in the deeper water.

The B.O.D. of Christie Pond was relatively high in both surface

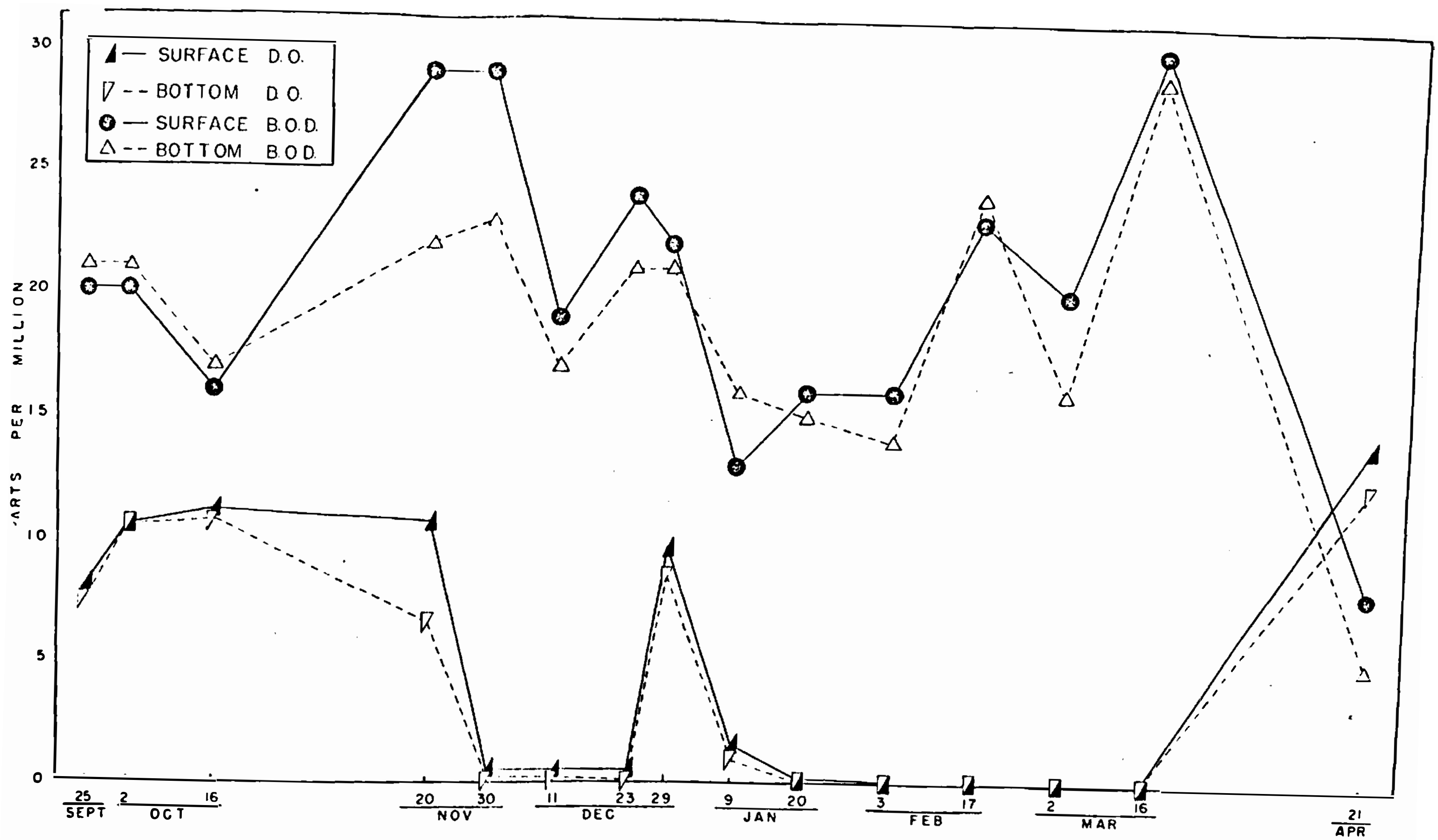

Figure 3. Dissolved Oxygen and Biochemical Oxygen Demand Levels in Christie Pond, Winter 1959-60.

and bottom waters during the entire study. An increase in the surface B.O.D. shortly after ice cover probably represents the die-off of the phytoplankton and zooplankton which are mostly found in the water of the euphotic zone. They supply a readily oxidizable suspended organic demand as they slowly sink to the bottom. This organic demand is probably responsible for the sharp decrease in dissolved oxygen of the surface and bottom waters to less than 1 p.p.m. between November 20 and November 29.

The dissolved oxygen remained at less than 1 p.p.m. till December 29, when the oxygen content of both the surface and bottom waters reached 9.7 p.p.m. and 8.6 p.p.m. respectively. The increase in the dissolved oxygen concentration was a result of runoff which occurred during the previous week of warm weather in which all of the snow melted and about one inch of rain fell. The runoff was enough to raise the pond about 45 cm. Within 11 days the dissolved oxygen in the surface water was below 2 p.p.m. and in the bottom water below 1 p.p.m. After a period of 22 days, the dissolved oxygen was below 1 p.p.m. in the surface water. After January 20, and until the spring break-up, the oxygen content remained at 0.0 p.p.m. in both surface and bottom waters.

The influx of melt and rain water during the warm rainy week previously mentioned diluted the pond water which caused a drop of a high surface B.O.D. of 22 p.p.m. to 13 p.p.m. The bottom B.O.D. reduction was not as pronounced indicating a more thorough mixing of the fresh and surface waters. The 13 p.p.m. surface B.O.D. was the lowest observed in Christie Pond during the study, and both the surface and bottom B.O.D.'s exhibited a steady increase to a high of 30 p.p.m. and 29 p.p.m. for surface and bottom waters, respectively just before the spring break-up.

The steady increase in B.O.D. of the water was probably related to the developing anaerobic conditions which were first noted on January 20. The water smelled of hydrogen sulfide gas and a test for this gas showed approximately 0.5 p.p.m. in the bottom waters of the pond. The surface-water test was negative. On the same date carbon dioxide content was 13 p.p.m. and 17 p.p.m. in surface and bottom waters respectively. The concentrations of both gases increased with time; and, on March 16, the hydrogen sulfide test indicated about 2 p.p.m. in both the surface and bottom waters; and carbon dioxide values of 46 p.p.m. in the surface water and 45 p.p.m. in the bottom water were determined. Ammonia increased from just over 1 p.p.m. on November 30 to 3.2 p.p.m. and 3.3 p.p.m. in the surface and bottom waters respectively on March 16.

The production of these gases by anaerobic bacteria can be related to the increasing B.O.D. in several ways. During the reduction processes caused by these bacteria, oxygen may be taken from the sulfates, phosphates, and nitrates in the water. Anaerobic bacteria also attack many stable organic compounds which are not easily reduced under aerobic conditions. Their action on these compounds leaves residues which are easily oxidized in the presence of dissolved oxygen. When waters in an anaerobic condition are set up as B.O.D. tests, the oxygenated dilution water provides a source of oxygen. This oxygen is utilized in the oxidation of the initial organic content but also some will be used in reforming the sulphates, phosphates and nitrates, and in the oxidation of residues resulting from the anaerobic bacterial action. Therefore, the oxygen demand of water resulting from anaerobic conditions will cause a considerable increase in incubated B.O.D. over that expected with aerobic conditions.

The light penetration measurements through snow, ice and water on Christie Pond are compiled in Table I. The results here confirm those found by previous investigators. In general, light penetration through ice conditions encountered in the pond would have been sufficient to establish a euphotic zone of considerable depth if the ice was free from snow cover.

Penetration of light through ice which was free of snow varied from the penetration of 31.6 percent of the incident light through 25.4 cm. of partly cloudy ice to 1.2 percent penetration through 78.74 cm. of ice which was cloudy for 5.08 cm. on top and the bottom 15.24 cm. of which was slushy. The slushy ice was probably largely responsible for the small amount of penetration.

The degree of cloudiness of the ice is another factor in light penetration. For instance, on one occasion 6.5 percent of incident light penetrated 33.1 cm. of cloudy ice and in another instance 22.6 percent penetrated 34.3 cm. of cloudy ice. The former ice condition was much more opaque than the latter although both ice conditions were termed cloudy. There were no determinations made of the degree of cloudiness in the ice observed in this study.

TABLE I. LIGHT PENETRATION THROUGH ICE, SNOW AND WATER IN CHRISTIE POND, WINTER 1959-60

Date	Ice		Snow Cover		Percent of Incident Light Penetrating Ice		Lower Boundary of Euphotic Zone Below Under Surface of Ice in cm.		
	Depth in cm.	Condition	Percent Cover	Depth (cm.) and Type	Clear	Snow Covered	Clear	Cover	Average
11-20-59	38.1	Cloudy	None	---	6.5	---	30.5	---	---
11-30-59	25.4	Partly cloudy	98	10.2 loose	31.6	0.89	61.0	0.0	1.3
12-11-59	26.7	Upper half cloudy, lower half clear	98	3.8 loose	11.8	2.6	89.0	16.5	17.8
12-23-59	34.3	Cloudy	90	2.5-5.1 compacted	22.6	7.6	74.9	49.5	52.1
1-9-60	42.5	Upper half cloudy, lower half clear	40	1.3 compacted	---	6.8	---	43.8	---
1-20-60	48.2	Top 5 cm. cloudy, rest clear	50	0-5.1 compacted	7.7	5.0	45.6	28.0	36.8
2-3-60	59.7	Top 7.6 cm. cloudy, rest partly cloudy	45	2.5 loose	7.0	0.3	54.6	0.0	29.8
2-17-60	62.2	Clear	50	---	7.5	0.6	16.5	0.0	8.3
3-2-60	75.0	Top Cloudy. Bottom 15.2 cm. slushy	90	1.3 crusty	0.7	0.1	0.0	0.0	0.0
3-16-60	78.7	Top 5.1 cm. cloudy, bottom 15.2 cm. slushy	100	12.7 loose	0.2	0.03	0.0	0.0	0.0

Snow cover is definitely a limiting factor in the penetration of light through ice. Christie Pond was 50 percent or more snow-covered during most of the study. Measurements under snow conditions indicate that 2.5 cm. or more of fresh or loose snow on the ice will inhibit almost all light penetration. Compacted snow did not inhibit light penetration to the extent that fresh or loose snow did. The individual interfaces of the snow crystals in compacted snow are forced tightly together giving it much the same effect as ice on light penetration. In loose snow there are many spaces between the crystal interfaces. Light is reflected among these spaces resulting in considerable loss due to reflection. On one occasion the pond was covered with 2.5 to 5 cm. of compacted snow. There was 7.6 percent of the incident light penetrating 34.3 cm. of cloudy ice under this compacted snow cover.

Turbidity of the water is also an important factor in light penetration through water. Turbidity in parts per million under ice cover in Christie Pond are listed in Table IV. The effect of turbidity can be seen by comparing the depths to which one percent of the incident light penetrated and the percent of incident light which penetrated the ice. On February 3, 7.6 percent of the incident light was penetrating the ice, and one percent of the light was penetrating to 54.6 cm. beneath the ice. At this time the turbidity of the surface water was 33 p.p.m. By contrast, on February 17, 7.5 percent of the incident light was penetrating the ice, and one percent was penetrating to only 16.5 cm. beneath the ice. The turbidity of the upper water was 48 p.p.m. in this case. In the above example, an increase of 15 p.p.m. turbidity decreased the depth of the euphotic zone by 38.1 cm., clearly indicating the effect of turbidity on light penetration through water. Turbidity measurements were made on surface and bottom waters from all samples collected in Christie Pond during the study. Turbidity becomes of greatest importance under ice cover; and, in general, the turbidity of the surface waters has the greatest effect on light penetration. An increase in such turbidity reduced light penetration as discussed above.

The light-and-dark-bottle test was used in an effort to measure the respiration of Christie Pond. The results of this test demonstrated two things: the oxygen production was insignificant and the B.O.D. of the pond was high. Both the light and dark bottles had an initial dissolved oxygen content of 4.1 p.p.m. After a 48 hours period the light bottle had 1.4 p.p.m. dissolved oxygen, losing 2.7 p.p.m. dissolved oxygen, and the dark bottle had 1.3 p.p.m. dissolved oxygen, losing 2.8 p.p.m. dissolved oxygen. The 0.1 p.p.m. higher dissolved oxygen content of the light bottle shows that only a very slight amount of oxygen was being produced. The losses experienced by both the light and dark bottles confirms the high B.O.D. of the water as demonstrated by incubated B.O.D. tests discussed previously.

It is believed that all fish in the pond died. As noted before, fathead minnows existed in the pond when the study was initiated. On November 30, the dissolved oxygen was 0.5 p.p.m. in the surface waters and 0.2 p.p.m. in the bottom water (Figure 3). At this time it was noticed that backswimmers, (Notonecta sp.), were coming to the surface after the hole was drilled in the ice. No fish were seen. On December

11, the oxygen content of the surface and bottom waters was the same as on November 30. On this date fathead minnows appeared in the hole and seemed to be somewhat distressed. Some dead backswimmers were seen and many others appeared moribund. This was the last time any live aquatic organisms were seen while the pond was in the winter condition. On December 23, the dissolved oxygen of the surface water was 0.5 p.p.m. and the bottom waters continued at 0.1 p.p.m. When a sample hole was drilled in the ice, the last few centimeters of ice contained the bodies of a number of backswimmers and fathead minnows. Also a few dead of each of these animals floated to the surface of the hole. It seems likely that all of the backswimmers and fish died between December 11 and 23, probably as a result of suffocation due to low dissolved oxygen content in the water. Other gases which are capable of bringing death to fish did not appear in concentrations high enough to be toxic during the period in which the fathead minnows and backswimmers died.

The final samples on Christie Pond were taken on April 21. At this time the pond had been ice-free for about two weeks but weather conditions prevented access to it.

The results of the tests on the final samples show the pond was relieved of its winter stagnation. The oxygen increased to 14.2 p.p.m. and 12.4 p.p.m., and the B.O.D. dropped to 8 and 5 p.p.m. in the surface and bottom waters, respectively. The development of these new conditions was the result of the melt waters flowing into the pond and to atmospheric reaction.

McNeil Pond

McNeil Pond did not suffer the severe winter stagnation that Christie Pond experienced, but winter-kill conditions did develop and had there been fish present in the pond they probably would not have survived.

The dissolved oxygen and B.O.D. values determined on McNeil Pond are plotted in Figure 4. This graph illustrates that the dissolved oxygen increased from the time the study was initiated until a short time after ice cover. During this period the water in the pond was cooling and therefore its ability to contain more dissolved oxygen increased as previously discussed. Absorption of oxygen from the atmosphere was probably responsible for a small part of the increase. The large portion of the increase was likely the result of photosynthetic activity. This can be explained by the fact that after ice cover the dissolved oxygen in the surface waters continued to increase till December 4 while the bottom waters began to drop by the same date. From Table II it can be noted that on December 4 there was sufficient light penetrating into the upper waters to permit photosynthesis while the bottom waters were below the depth of the euphotic zone.

From December 4 to January 13 the dissolved oxygen steadily decreased from 13.9 p.p.m. and 7.7 p.p.m. to 0.3 p.p.m. and 0.2 p.p.m. in the surface and bottom waters, respectively. This reduction was probably the result of two things. First, the phytoplankton population was diminished thereby causing a reduction in the total oxygen production. This reduction was great enough that dissolved oxygen consumed by the

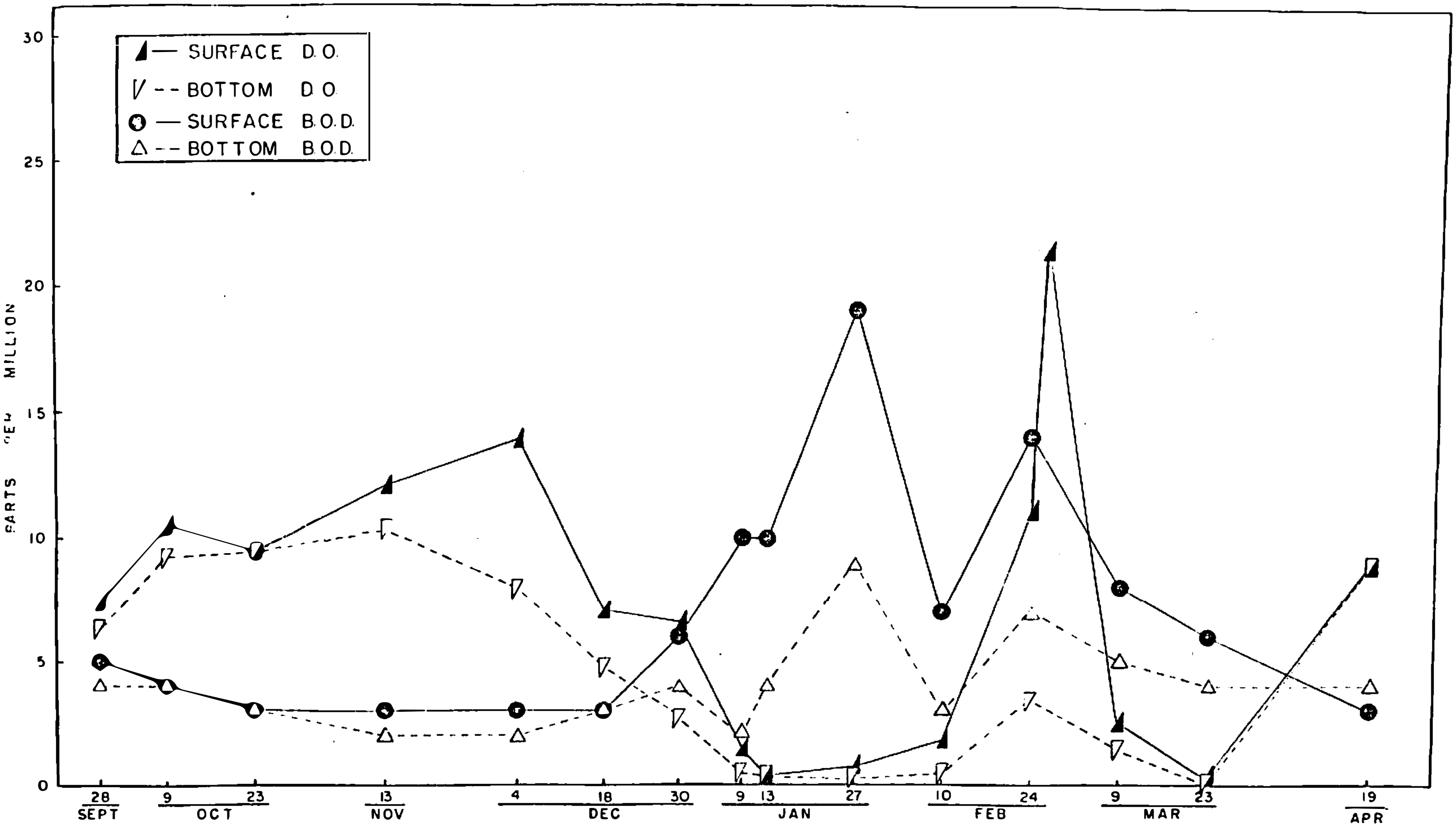

Figure 4. Dissolved Oxygen and Biochemical Oxygen Demand Levels in McNeil Pond, Winter 1959-60.

B.O.D. of the pond was more than that which was being produced. Secondly, there was an increase in the B.O.D. of the pond which was noted on December 30. McNeil Pond experienced the same warm rainy weather the last week in December as Christie Pond. The result was also an influx of melt and rain waters which raised the pond water level about 45 cm. Included in this runoff was water from a silage pit to which the increase in B.O.D. can be largely attributed.

After January 13 the dissolved oxygen began a slow increase. Then on February 24 it increased to 11.1 p.p.m. in the surface waters and on the 26th it was 21.4 p.p.m. at a depth of 45.7 cm. below the under surface of the ice. The sharp increase in dissolved oxygen on these dates was the result of an algae bloom at which time large numbers of algae were observed. It then took a sharp decline and on March 9 was 2.6 p.p.m. in the surface water. A slow decline followed and on March 23, the last sampling before break-up, the dissolved oxygen was 0.2 p.p.m. in the surface water and 0.0 p.p.m. in the bottom water. The bottom sample on this date was the only time oxygen was found to be 0.0 p.p.m. in McNeil Pond during the study.

The increase in dissolved oxygen during the algae bloom was not limited to the surface water, as a slight increase also occurred in the bottom water. The euphotic zone on February 24 (Table II) did not extend to a depth which would permit photosynthesis in the bottom water. This would indicate there was some current present under the ice which brought some of the oxygenated surface water to the deep water. Diffusion of oxygen through undisturbed water is so slow that it is unlikely that diffusion could have accounted for the transfer of oxygenated surface water to the bottom.

The algae bloom was of short duration. The algae began to increase in numbers about February 10 and evidently reached their peak about February 26 when the dissolved oxygen reading was the highest and then died. The rapid decrease in dissolved oxygen after the algae bloom was caused by the increased B.O.D. resulting from the dead algae. A direct relationship between dissolved oxygen and B.O.D. at this reading will be noted in Figure 4.

In general the B.O.D. of McNeil Pond was low. From the time the study was initiated until the late December runoff, the B.O.D. of the surface or bottom waters never exceeded 5 p.p.m. After the runoff entered the pond the last week in December the B.O.D. increased to 10 p.p.m. in the surface waters. Most of this increase can be attributed to drainage from the silage pit. Following this, two simultaneous increases and decreases of the B.O.D. in both surface and bottom waters were noted. The first was on January 27 and the second on February 24. The latter occurred during the algae bloom previously discussed. Both of these fluctuations were probably the result of large algae concentrations. The increase in B.O.D. resulted from the readily decomposable dead algae, and the decrease occurred when the organic demand resulting from the algae was satisfied. Although there was no corresponding increase or decrease in dissolved oxygen with that of the B.O.D., on January 27 an undetected algae bloom is likely the cause. As indicated previously, an algae bloom may be short-lived and the resulting increase and decrease in dissolved oxygen sharp and sudden. Therefore, it is very possible the fluctuation in dissolved oxygen may have occurred unnoticed.

Light penetration data through ice, snow and water in McNeil Pond is compiled in Table II.

From this table it can be noted that ice, when free from snow cover, did not greatly affect the light penetration as far as a sufficient euphotic zone depth was concerned. Ice depths of over 76.2 cm. transmitted light for a considerable depth.

In McNeil Pond as in Christie Pond, snow cover was the main factor limiting light penetration. Over 5 cm. of loose snow entirely or almost entirely impeded light penetration. Again it was found that compacted snow did not reduce light penetration to the extent that loose snow did.

The turbidity of the water under ice cover in McNeil Pond is listed in Table IV. Turbidity in this pond was low with only one high reading observed. After the late December runoff and rain the turbidity in the surface waters was 54 p.p.m. This was the highest reading recorded and all other readings were 32 p.p.m. or below. Turbidity of water in McNeil Pond was not a great factor in light penetration.

The light-and-dark-bottle test was conducted during the algae bloom observed on February 24. The light and dark bottles were lowered under the ice on February 26. It is believed this was after the peak of the algae bloom as indicated by the test. The initial dissolved oxygen content was 21.4 p.p.m. of both bottles and 48 hours later the light

TABLE II. LIGHT PENETRATION THROUGH ICE, SNOW AND WATER IN McNEIL POND, WINTER 1959-60

Date	Ice		Snow Cover		Percent of Incident Light Penetrating Ice		Lower Boundary of Euphotic Zone Below Under Surface of Ice in cm.		
	Depth in cm.	Condition	Percent Cover	Depth (cm.) and Type	Clear	Snow Covered	Clear	Cover	Average
12-4-59	19.0	Clear, cloudy streak in center	98	8.9 loose	42.9	2.9	---	148.9	---
12-18-59	24.1	5.1 cm. cloudy on top, rest clear	65	3.8 loose	49.2	8.2	---	219.7	---
12-30-59	24.1	1.3 cm. frozen slush, rest clear	25	0-1.3 loose	23.6	19.3	67.3	54.6	64.1
1-6-60	34.9	5.1 cm. cloudy on top, rest clear	50	5.1-10.2 loose	18.2	2.7	81.9	18.4	50.2
1-13-60	36.8	5.1 cm. cloudy on top, rest clear	45	1.3 compacted	20.5	11.3	113.0	84.5	101.6
1-27-60	55.9	5.1 cm. cloudy on top, rest clear	75	6.4 loose	13.8	1.1	55.9	0.0	21.6
2-10-60	55.2	5.1 cm. cloudy on top, rest clear	80	2.5-3.8 loose	19.0	1.0	97.2	0.0	19.0
2-24-60	61.0	Clear	80	5.1 loose	12.25	1.0	48.2	0.0	9.5
3-9-60	75.6	7.6 cm. cloudy on top, rest clear	100	12.7 loose	7.3	0.02	43.2	0.0	---
3-23-60	74.2	2.5 cm. cloudy on top, rest clear	95	3.8 compacted	20.7	2.1	106.0	32.4	35.6

bottle had 17.6 p.p.m. dissolved oxygen and the dark bottle contained 16.5 p.p.m. dissolved oxygen. The loss in the light bottle indicates that dead or decaying algae were present although there was enough photosynthetic activity to produce a small amount of oxygen. The dark bottle result showed a large B.O.D. of the pond water at this time which was also noted from the incubated B.O.D. test.

Between January 6 and February 10 the dissolved oxygen in both the surface and bottom waters was below 1 p.p.m. If fish had been present in the pond, they likely would have died during the period of low dissolved oxygen.

The last samples taken on McNeil Pond were after the spring break-up. The dissolved oxygen had increased to 8.9 p.p.m. in both the surface and bottom waters. The B.O.D. values did not change to any degree as they were low previous to the spring break-up.

Ullman Dugout

Ullman Dugout was utilized as check against Christie Pond and McNeil Pond during this study. It was chosen for this purpose because of its recent construction. It, therefore, would have little organic matter in its waters.

The dissolved oxygen and B.O.D. measurements made on Ullman Dugout are plotted in Figure 5.

Dissolved oxygen content of the water in this pond did not exhibit any great fluctuations. The dissolved oxygen increased slightly from the time the study was initiated to shortly after ice cover. This increase in dissolved oxygen might be explained by the lowering water

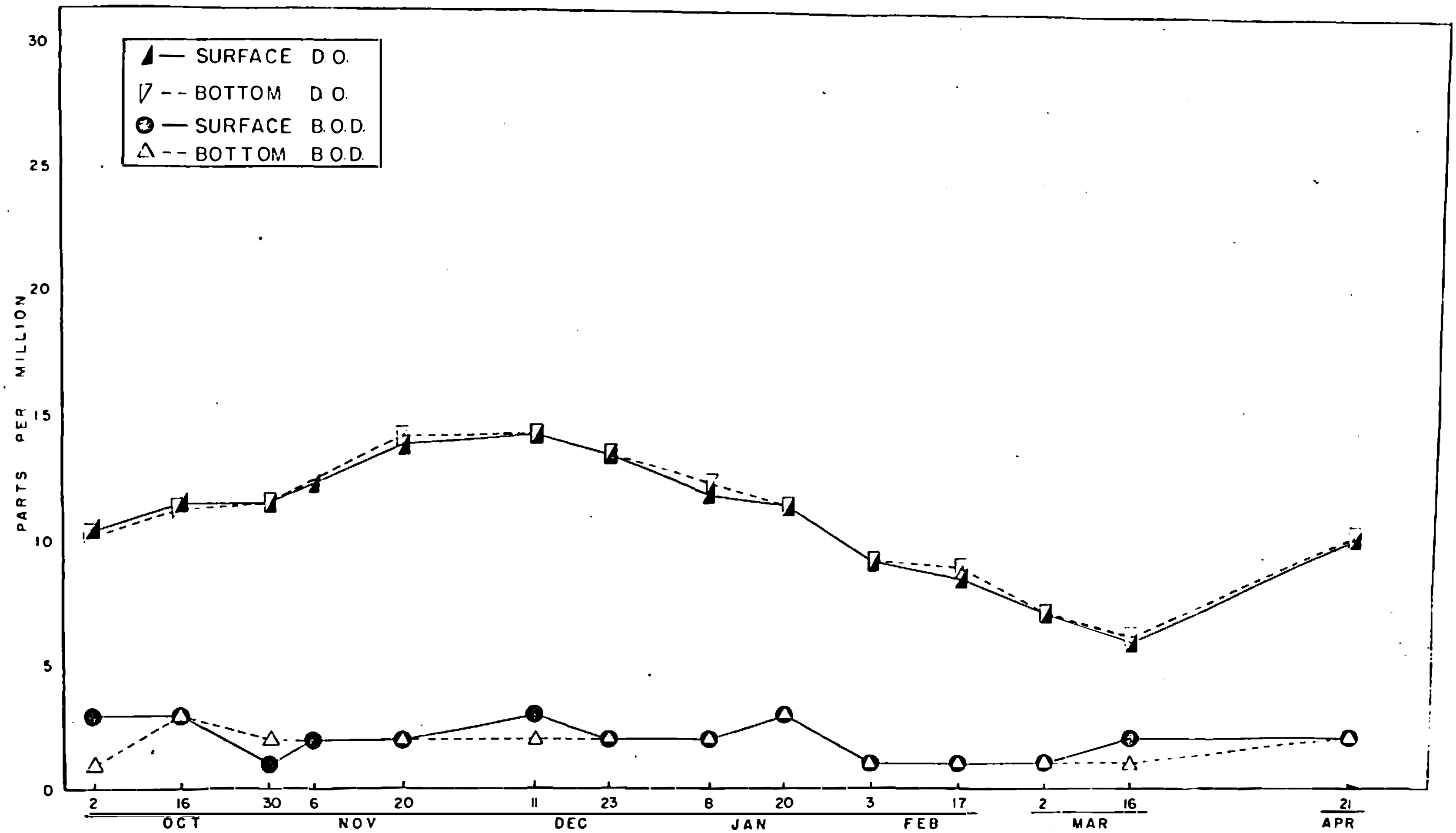

Figure 5. Dissolved Oxygen and Biochemical Oxygen Demand Levels in Ullman Dugout, Winter 1959-60.

temperatures during this period and a small amount of photosynthetic activity as discussed previously in the Christie and McNeil Ponds.

After December 11 the dissolved oxygen in the dugout started a small but steady decrease from just over 14 p.p.m. in the surface and bottom waters to 5.9 p.p.m. in the surface water and 6.1 p.p.m. in the bottom water on March 16, the last sampling date before the spring break-up. The slightly higher dissolved oxygen content in the bottom water can be attributed to the fact that the B.O.D. of the bottom water was lower than the surface B.O.D. at this date.

The B.O.D. of Ullman Dugout was extremely low during this study. Neither the surface or bottom waters had a B.O.D. that exceeded 3 p.p.m. This indicates the waters of the dugout were very low in organic content and probably contained very little phytoplankton.

Light penetration data through ice, snow and water on Ullman Dugout is listed in Table III. In all cases but one, more than one percent of the incident light penetrated to the bottom of the dugout. The one exception was on March 16 when only 0.9 percent of the incident light penetrated 71.1 cm. of ice covered with 7.6 cm. of snow.

When more than one percent of the incident light penetrated to the bottom of the pond through snow covered with ice, no attempt was made to clear the ice and made a comparable light penetration measurement through cleared ice.

Snow cover on Ullman Dugout was not a limiting factor as it was on Christie Pond and McNeil Pond. Only on March 16 did snow prevent light penetration into the pond. On December 11 and 23 snow cover was

TABLE III. LIGHT PENETRATION THROUGH ICE, SNOW AND WATER IN ULLMAN BOGUE, WINTER 1959-60

Date	Ice		Snow Cover		Percent of Incident Light Penetrating Ice		Lower Boundary of Euphotic Zone Below Under Surface of Ice in cm.		
	Depth in cm.	Condition	Percent Cover	Depth (cm.) and Type	Clear	Snow Covered	Clear	Cover	Average
11-20-59	30.4	Cloudy	None	None	12.5	---	182.8	---	---
12-22-59	35.6	Cloudy on top, rest clear	10	---	33.8	---	177.8	---	---
12-23-59	35.8	5.1 cm. cloudy on top, rest clear	20	---	38.8	---	191.8	---	---
1-8-60	43.9	0.6 cm. cloudy on top, rest clear	99	0.6 loose	---	17.9	---	170.2	---
1-20-60	49.5	5.1 cm. cloudy on top, rest clear	98	2.5 loose	---	13.3	---	163.8	---
2-3-60	58.4	Clear	90	3.2 compacted	---	88.5	---	124.4	---
2-17-60	63.5	10.8 cm. milky on top, rest clear	None	---	78.8	---	119.4	---	---
3-2-60	66.0	2.5 cm. cloudy on top, rest clear	100	2.5-10.2 loose	---	6.8	---	147.3	---
3-16-60	71.1	3.8 cm. cloudy on top, rest clear	100	7.6 loose	12.2	0.9	152.4	0.0	---

present on the dugout but it was limited to the ice near the shores and it is doubtful that it had any appreciable effect on total light penetration into the water.

Turbidity of the water in Ullman Dugout under ice cover is listed in Table IV. The turbidity of neither the surface nor the bottom waters ever exceeded 10 p.p.m. Because the turbidity of the water was constantly low and there was excellent penetration of light through the water, turbidity was not a factor in preventing light penetration through the water of the Ullman Dugout during this study.

The results of the light-and-dark-bottle test conducted on Ullman Dugout indicate that the pond was nearly in a state of equilibrium, that is, as much oxygen was being produced as consumed. The initial dissolved oxygen in light and dark bottles was 8.4 p.p.m. After a 48 hour period the light bottle contained 8.3 p.p.m. dissolved oxygen, a loss of 0.1 p.p.m. and the dark bottle contained 8.1 p.p.m. dissolved oxygen, a loss of 0.3 p.p.m. from the initial reading. The difference of 0.2 p.p.m. between the light and dark bottles indicates there was phytoplankton present to produce enough oxygen to offset the dissolved oxygen consumption by the organic demand to a small degree. This is probably why the decrease in the dissolved oxygen content of the pond was not sharp.

The trout planted in the dugout survived the winter. No winterkill conditions developed and no mortality from other factors was noted. The fish were observed surface feeding a short time after the spring break-up.

On April 21 the final samples were collected from Ullman Dugout.

The spring break-up had occurred and the pond was ice free. Dissolved oxygen had increased to just over 10 p.p.m. in both the surface and bottom waters. The B.O.D. made no appreciable change.

TABLE IV. TURBIDITY UNITS (PARTS PER MILLION) UNDER ICE COVER IN ULLMAN DUGOUT, McNEIL POND AND CHRISTIE POND, WINTER 1959-60

Ullman Dugout			McNeil Pond			Christie Pond		
Date	Surface	Bottom	Date	Surface	Bottom	Date	Surface	Bottom
11-20-59	10	--	12-4-59	6	4	11-20-59	58	--
12-11-59	7	7	12-18-59	8	7	11-30-59	45	25
12-23-59	0	0	12-30-59	54	25	12-11-59	36	34
1-9-60	6	7	1-6-60	32	15	12-23-59	36	30
1-20-60	4	6	1-13-60	21	13	12-29-59	37	33
2-3-60	6	6	1-27-60	24	21	1-9-60	29	28
2-17-60	10	8	2-10-60	21	17	1-20-60	34	32
3-2-60	6	6	2-24-60	29	21	2-3-60	33	33
3-16-60	7	7	3-9-60	23	20	2-17-60	48	45
			3-23-60	21	21	3-2-60	39	46
						3-16-60	52	56

SUMMARY AND CONCLUSIONS

Winter kill is a major problem in fisheries management in the northern Great Plains area. It is generally caused by a dissolved oxygen depletion in the water resulting from aerobic decomposition of organic matter in the water. Shallow, fertile lakes more commonly suffer winter kill than do the deep, clear lakes. At times other factors may be involved in winter kill.

Dissolved oxygen is supplied to an aquatic environment mainly as a by-product of photosynthetic activity of green plants. Aeration may occasionally provide an important source of dissolved oxygen.

Under ice cover photosynthesis of green plants may be the only source of oxygen production. Many times light penetration through ice, snow and water may become the critical factor in the survival of aquatic organisms.

The dissolved oxygen test is the primary method of determining the winter condition of a lake. The biochemical-oxygen-demand test and light penetration measurements through ice, snow and water are also important. Other tests are turbidity measurements, light-and-dark-bottle tests, and tests for various dissolved gases such as carbon dioxide, hydrogen sulfide and ammonia.

This study was undertaken in an attempt to clarify some of the winter-kill phenomena. Two farm ponds and a dugout pond used as a check were chosen for the study. The tests mentioned above were used to determine if they could be correlated to provide an index for predicting winter kill. The study was initiated on September 25, 1959 and concluded on April 26, 1960.

Two of the study ponds, Christie Pond and Ullman Dugout, had fish populations at the start of the investigation. McNeil Pond contained no fish.

Christie Pond suffered a severe winter kill. Dissolved oxygen was 0.0 p.p.m. for a considerable period of time and the B.O.D. was consistently high. Anaerobic conditions developed in the pond and carbon dioxide, hydrogen sulfide and ammonia were all present in toxic concentrations.

Light penetration through ice in Christie Pond was usually sufficient to establish a euphotic zone of considerable depth. Loose snow covering the ice greatly reduced light penetration whereas compacted snow affected light penetration to a lesser degree. Turbidity was found to be an important factor in reducing light penetration through water. It is believed there was complete winter kill in this pond.

McNeil Pond suffered winter-kill conditions but not severe. Dissolved oxygen was below 1.0 p.p.m. for only a short time in the study. The B.O.D. of the pond was relatively low. No anaerobic conditions or harmful gases were noted in the pond. As in Christie Pond, snow cover on the ice was the main factor limiting light penetration. Turbidity of the water in this pond was not a factor in light penetration.

Ullman Dugout provided a check on the Christie and McNeil ponds. Winter-kill conditions were never closely approached in the dugout. Dissolved oxygen levels were consistently high while the B.O.D. levels were consistently low. Light penetration was high through ice, snow and water conditions encountered during the study. The fish in the dugout survived the winter.

From the results of the investigation on the three ponds, several tentative conclusions can be made:

1. Low dissolved oxygen content in the water is a significant cause of fish mortality.
2. Oxygen released as a by-product of photosynthetic activity of phytoplankton is a source of dissolved oxygen under ice cover.
3. The B.O.D. test indicates the degree of probability of winter kill developing in a farm pond.
4. Anaerobic conditions increase the B.O.D. of a pond.
5. The B.O.D. increases with the decomposition of large algae populations.
6. Ice usually is not a limiting factor in preventing sufficient light penetration to an aquatic environment, but 2.5 cm. or more of loose snow can be considered a critical factor in the penetration of light, whereas 5 cm. of compacted snow is not critical.
7. An increase in the turbidity of the water will decrease the distance that light will penetrate the water.
8. The occurence of gases such as carbon dioxide, hydrogen sulfide and ammonia in concentrations which are toxic to fish was probably not a factor in mortality of fish in the winter conditions studied.

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