Original: Fish Division
cc: Institute for Fisheries Research
Education-Game
Mr. Harold Hughes
Mr. Robert Fortney
Dr. G. P. Cooper
Mr. G. N. Washburn

INSTITUTE FOR FISHERIES RESEARCH
DIVISION OF FISHERIES
MICHIGAN DEPARTMENT OF CONSERVATION
COOPERATING WITH THE
UNIVERSITY OF MICHIGAN

ALBERT S. HAZZARD, PH.D.
DIRECTOR

ADDRESS
UNIVERSITY MUSEUMS ANNEX
ANN ARBOR, MICHIGAN

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WINTERKILL INVESTIGATIONS (1944-45) ON MICHIGAN LAKES

by

G. P. Cooper and G. N. Washburn

A heavy mortality of fish occurred during the winter of 1944-45 in numerous lakes, especially in the southern part of Michigan. This mortality, referred to as a winterkill, can be attributed to adverse environmental conditions which develop in certain lakes when these lakes are covered for a protracted period by a thick layer of snow. Presumably the thick layer of snow shuts out so much of the sunlight from penetration into the lake, and thereby so reduces the photosynthetic production of oxygen by aquatic plants (especially plankters), that the normal processes of oxygen consumption in the water can reduce the dissolved oxygen to a very low, or vanishing point.

An intensive study of winterkill conditions in Michigan lakes was made by John Greenbank during the winters of 1937 to 1943 (Institute Reports Nos. 853 and 853a). Some earlier observations on winterkill in Michigan lakes were summarized in Institute Reports 346 and 351. The present report, on observations made during the winter of 1944-45, includes the data given in Institute Memoranda Nos. 180 and 181.

Water Analyses during the Winter

Winterkill of an extensive nature is sporadic in occurrence in southern Michigan lakes. A severe kill occurred during 1935-36, and a light kill during the winters of 1939-40 and 1940-41.[1] When it was realized that weather conditions were such as to probably cause a kill during the winter of 1944-45, observations were begun on a group of lakes in Washtenaw and Jackson counties in order to determine the extent of oxygen depletion in these lakes and to know the lakes on which a winterkill was taking place. As the field studies were continued, it was further anticipated that information could be obtained on the minimum oxygen requirements of some of our common fish species. Also, on one lake, a small area was flooded and cleared of snow (by pumping water onto the ice) in an attempt to evaluate this method of alleviating winterkill conditions. In a similar flooding operation on Green Lake in 1942-43, Greenbank (Report No. 853a) did not have a good opportunity to evaluate this method because of weather conditions subsequent to the flooding.

The lakes on which winter observations were made, their geographic locations, and the locations of water-analysis stations on each are as follows:

Name of lake	County	Town	Range	Sections	Station on lake where samples were taken
Green	Washtenaw	1 S.	3 E.	21,22,27,28	Numerous stations over the entire lake
Sugarloaf	Washtenaw	1 S.	3 E.	31,32	N.E. central part of lake
First Sister	Washtenaw	2 S.	5 E.	25	Center of lake, and at "air hole"
Batteese	Jackson	1 S.	1 E.	9	Near center of lake
Grass	Jackson	2 S.	2 E.	29,32	200 yds. off middle of E. shore
Goose	Jackson	2 S.	1, 2 E.	24,25,19,30	200 yds. off N. W. shore
Merkle	Jackson	1 S.	2 E.	14,15	Near center of lake
Mud	Washtenaw	1 S.	3 E.	31	Near center of lake
Mill	Washtenaw	2 S.	3 E.	4,5	Near center of lake
Cavenaugh	Washtenaw	2 S.	3 E.	8	200 yds. off middle of east shore
Four Mile	Washtenaw	1, 2 S.	4 E.	33,4	Center of N. half of lake
Cassidy	Washtenaw	1 S.	3 E.	33	Near center of lake
Big Silver	Washtenaw and Livingston	1 S., 1 N.	4 E.	3,4,33	In N. W. bay
Deep	Oakland	4 N.	7 E.	27	Near center of lake

[1] See Institute Report No. 853 by John Greenbank

At the beginning of the field study, observations were made on only a few of the above lakes. Additional lakes were visited as reports indicated that a winterkill might be expected. For Deep and Big Silver lakes there was no basis for suspecting a winterkill; rather, the observations were made on these lakes as a matter of interest in showing the contrast between lakes which are subject to kill and those which are not. For Four Mile and Cavenaugh lakes, a suspected possibility of winterkill conditions was not verified by the single set of analyses on each.

During the period from January 12 to March 5, 1945, field observations were made on the lakes in the above list; some of the lakes were visited several times, others only once. At each visit observations were made on the condition of snow and ice cover on the lake, on the prevailing weather conditions, and tests were made on dissolved oxygen in water samples from various depths. The water samples were collected with a covered-can type[2] of sampler on all lakes, except Deep Lake where a Kemmerer sampler was used; and all oxygen analyses were made by the unmodified Winkler method. Samples for oxygen analyses were collected at numerous stations on Green Lake (discussed later), at two stations on First Sister, and at one station on the remaining lakes. The locations of these oxygen stations, on all except Green Lake, were near the center of each lake and/or near the deepest water. The stations on Goose and Grass were considerably off-centered, but the depths of these two lakes are reported to be uniformly very shallow. It is assumed that the results of analyses at these single stations would be fairly representative of conditions throughout each lake, with the possible exception of areas near inlets and outlets. For most lakes the depth of the deepest oxygen sample represents nearly the maximum depth (or a fair proportion of it) of the lake.

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[2] This general type of sampler is figured on p. 167 of the New York State Biological Survey Report No. V (1930), and is referred to on p. 169 of that report as the "Illinois sampler used by the Illinois State Water Survey. (See Bulletin Illinois State Water Survey No. 16, p. 197.)"

Ice covers on these lakes in the Washtenaw-Jackson area averaged about 6 inches in depth on January 12, approximately 10 inches on January 29, and 12 inches on February 12 and thereafter during the analyses.

These lakes in the Washtenaw-Jackson area were covered by a heavy snowfall on December 11, 1944 and this snow cover remained as a complete blanket over all of the lakes practically continuously until February 15, 1945. This snow cover, measured frequently from January 12 to February 14, varied from 2 to 5 inches in depth and averaged about 3 inches. A 2-inch snowfall on January 22 and a 4-inch fall on February 7 about compensated for occasional thaws and packing. A light rain on February 9 had little effect in removing the snow. This 2 to 5 inches of snow cover was at times partly new, light snow, and at other times entirely compact and crusty snow; but throughout this period of December 11 to February 15, there was this continuous cover of 2 to 5 inches of snow of types known to be very effective in reducing light penetration. On February 14-15, there was a 24-hour thaw (temperature about 40° F., and light rain) which cleared most of the snow from all of these lakes; and the remaining snow was in small scattered patches of 1/4 to 1/2 inch in depth, which patches totaled, on February 16, about 1/4 the surface area of Green Lake, 2/3 the area of Four Mile Lake, and 3/4 the area of First Sister. But this remaining snow (on February 16) was so thin and compacted with water as to be quite transmissible to light. Thus, from the standpoint of light penetration, the lakes were practically cleared of their snow cover on February 15. These lakes remained free of snow cover for the duration of the study, i.e., through March 5.

There was very little water, from either rainfall or ice suppression and flooding, on the ice surface of these lakes from January 12 to February 14. The thaw and rain on February 14 to 15 produced considerable water on the ice surface, and much of this water poured into the lakes through occasional large drainage holes and numerous small holes along fracture cracks in the ice. Such thaw water accumulates until sufficient fractures develop in the buoyant ice to let the water through. Many of the tell-tale holes and drainage patterns on the ice were seen on the lakes after February 15. That this surface run-in water was potently charged with dissolved oxygen was indicated by the oxygen analyses at regular stations following this and subsequent thaws; and also by the two following tests: (1) On Green Lake, February 16, the day following the thaw, oxygen analyses were made at one run-in hole about 6 inches in diameter. This hole, through 12 inches of ice, had a thin layer of ice over it, having frozen over within the past 12 hours. A sample of the water from within this drainage hole had 12.85 p.p.m. of dissolved oxygen. (2) When an area of Green Lake was experimentally flooded on February 7, by pumping water onto the surface of the lake and melting down the snow, water was collected from a drainage pocket on the surface of the ice and found to have 10.14 p.p.m. Simultaneous samples from the lake itself (the water being pumped out) had from 0.16 to 0.31 p.p.m.

There was almost no thaw on these several lakes from February 16 to 20. There was considerable rain and thaw on February 21 and 22, some rain and thaw on February 23 to 26, very little thaw or rain on February 27 to March 1, some thaw on March 2 to 4, and a considerable thaw on March 5. The air temperature at noon on March 5 was 60° F., and ice on the lakes was getting porous and "rotten." Thus, up to March 5, there were three rather definite periods of rain and/or thaw, namely: February 14-15, February 21-26, and March 2-5. The significance of these thaws will be discussed later.

Of the fourteen lakes listed previously, oxygen analyses were made on one or more lakes on 16 different days during the period from January 12 to March 5. Green was visited on 15 days, Sugarloaf and First Sister on 8, and the others less frequently. The results of oxygen analyses on Green Lake are given in Table 2 and Figures 1 and 2, for the other lakes in Table 1 and Figure 1.

One definite conclusion from the present study is that in the majority of these 14 lakes there was a great reduction in dissolved oxygen during the winter. The extent and rate of reduction, and of later increase, can be indicated only for the period covering the dates of analyses (January 12 to March 5). Assuming that these lakes were near or at saturation of oxygen at the overturn last fall (a fairly safe assumption), their waters had undergone considerable loss of oxygen by the date of our first analyses on January 12. On that date Green Lake had 2.2 and 4.78 p.p.m. at 6 inches to 1 foot below the ice, and 1.33 and 1.10 p.p.m. at the bottom at depths of 5 and 7.5 feet. By January 12 oxygen in First Sister was down to 2.9 p.p.m. at the surface and 0.67 at the bottom (17 feet). In Sugarloaf and Batteese the surface oxygen values (5.41 and 7.84) were less than saturation at prevailing temperatures, and therefore less than their supposed values at the prece~~e~~ding fall overturn, but oxygen depletion in these lakes had not become so extreme as in Green and First Sister. From January 12 to February 5 the oxygen content in these four lakes decreased considerably and quite consistently. All seven of the lakes examined on February 5 (Tables 1 and 2) had less than 3 p.p.m. throughout, and four of the seven had less than 1 p.p.m. at all depths. During the second week in February, the lakes subject to oxygen depletion were in their most critical stage. Green, First Sister, Batteese, Goose, Merkle, and Grass had considerably less than 1 p.p.m. of oxygen at all depths; while Mud and Cassidy probably reached a minimum close to 1 p.p.m.

In most of the lakes a recovery in dissolved oxygen was started by the thaw on February 14-15 when the 3 to 4 inches of snow was melted and much of the resulting water ran into the lakes through holes in the ice. This run-in of oxygenated water affected only the upper one or two feet of lake water to an appreciable extent. The oxygen analyses for Green Lake (Stations B, 1, 2, 6, and 7) and First Sister on February 16 show the beginning of this recovery. From February 16 to 19 in Green Lake there was some loss of oxygen in the surface water, but this reduction apparently was at least partially due to a diffusion of oxygen to deeper water. Following the thaw and rain on February 21-26, Green, Sugarloaf, Grass, and Goose gave much higher oxygen values especially in surface waters (February 27 analyses); and following the March 2-5 thaw the four lakes examined showed a still further recovery. First Sister Lake had the poorest recovery up to March 5.

Green Lake was selected for an experimental attempt to alleviate winterkill conditions. By the end of January oxygen in this lake had been reduced to less than 1 p.p.m., and samples at seven stations (A to G)[3] showed that this low oxygen prevailed in all parts of the lake, even at the mouth of the inlet. On February 7 oxygen values at 4 stations (2, 4, 4a, and 6) did not exceed 0.31 p.p.m. Thus the lake afforded an excellent opportunity for the following attempt to rejuvenate its oxygen supply. An area was selected in the central part of the north half of the lake. This experimental area was flooded by pumping lake water onto the surface of the ice. Pumping was done on February 7, using a Jaeger 5-H. P. motor with centrifugal pump fitted with a 2 1/2-inch intake hose and a 2-inch outlet hose 15 feet long. We estimated the output of this pump at 150 g.p.m. Operating the pump for four hours (12 noon to 4 P.M.) flooded 3/8 of an acre (rough calculation), and this flooding partly melted and partly soaked down the 3 inches of snow on the area. From the standpoint of light penetration the entire area was cleared of its

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[3] Stations A to G were scattered over the area of Green Lake as follows: Station A was in the north-central part of the lake; Station B was at the center of the lake; Station C, 100 yds. off the west shore; Station D, 100 yds. off the northwest shore; Station E, 200 yds. off the southeast shore; Station F, in the south-central part of the lake; and Station G, 150 yds. off the mouth of the inlet.

blanket of snow. The water soaked out through the lower part of the snow cover for an additional 25 feet around the circumference of the 3/8-acre cleared area. During the night of February 7-8, about 4 inches of new snow was precipitated, completely blanketing the flooded area. So the flooding operation was repeated on February 9 when a 3-H. P. Briggs and Stratton motor and centrifugal pump was used.[4] This pump was fitted with a 3-inch intake hose and a 3-inch outlet with no hose attached. The output of this pump was estimated at 250 to 300 g.p.m. It was operated for four hours (10 A.M. to 2 P.M.), at the end of which a 1-acre plot, including the formerly flooded area, was cleared of snow. This new area was circular in outline and approximately 250 feet in diameter. In addition the water soaked out into the lower part of the snow cover for about 25 feet around the circumference of the cleared area. The 1-acre area of ice remained free of snow for the remainder of observations. Beneath this cleared area the lake was 3 to 4 feet deep, and the bottom had a luxuriant growth of rooted vegetation (mostly Potamogetons). As seen through several holes in the ice during January and February, these plants appeared to be slightly green in patches, but the general appearance of the vegetation was yellowish and scraggly.

A series of seven stations for oxygen analyses was set up consecutively in a line running north to south across the middle, and beyond the limits, of the 1-acre cleared area. Station 1, at the north end, was 150 feet from the edge of the cleared area; Station 2 was 50 feet outside the cleared area; Station 3, 25 feet inside the cleared area; Station 4, at the center of the cleared area; and Stations 5, 6, and 7, proceeding southerly, corresponded in relative position to Stations 3, 2, and 1, respectively. An additional Station (4a) was established 25 feet west of Station 4. Thus, Stations 3, 4, 5, and 4a were within the cleared area,

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[4] Mr. O. H. Clark assisted in this flooding.

while Stations 1, 2, 6, and 7 were outside of it in areas with 3 to 4 inches of snow cover. The objective in making oxygen analyses along this line of stations was to obtain answers to the following questions: (1) If a lake area is flooded and the snow cover thereby melted, to what extent does the subsequent run-in of surface water increase the dissolved oxygen in the lake? (2) How long does any beneficial effect last? (3) Will the aquatic plants respond, in short order, to the increased light in a cleared area and build up the oxygen content by photosynthesis? and (4) Is flooding a feasible method of preventing oxygen depletion and winterkill?

Greenbank (Institute Report No. 853) on Michigan lakes found that 2 to 5 inches of light snow or crusty snow transmits only about 2 per cent of light incident on the surface; while 6 to 10 inches of ice may transmit as much as 80 per cent or as little as 20 per cent of incident light, depending upon whether the ice is clear or cloudy (snow ice). He also gave figures to show that the percentage of incident light transmitted by ice is fairly comparable to that transmitted by a corresponding depth of water. Thus the effect of completely clearing a thick snow cover from a lake is to increase by about 50-fold the amount of light penetration, and to allow an illumination nearly comparable to conditions when the lake is free of ice. Therefore, it is concluded that our flooding operation on Green Lake restored an experimental area of illumination very favorable for plant photosynthesis.

Oxygen analyses were made along the line of stations (1 to 7) at frequent intervals from February 7 to March 5. Care was exercised to avoid contamination of these samples by water lying on the surface of the ice. The results of these analyses are given in Table 2 and in Figure 2. The oxygen analyses of February 7 at Stations 2, 4, 4a, and 6 were made just before the initial flooding, and the results indicated that dissolved oxygen under the area was very low (0.21, 0.16, 0.21, and 0.31 p.p.m. in surface samples; and 0.10, 0.10, 0.0, and 0.0 p.p.m. in bottom samples at 3 and 4 feet). Following the experimental floodings on February 7 and 9, oxygen analyses made on February 10 showed a striking increase in oxygen at the three stations (3, 4, and 5) within the cleared area in the surface samples (0-3 inches below the ice). This increase in oxygen had not involved the 3 and 4 foot (bottom) depths, except to a slight extent at Station 4. This increase in oxygen we attribute to the effect of surface run-in, rather than to increased photosynthesis, for the following reasons: (1) There had been only about 10 to 15 hours of daylight since the area was cleared which amount of time would not seem to be adequate to give by photosynthesis the amount of increase in oxygen which occurred; furthermore, assuming that photosynthesis might have caused the increase, it would be expected that the increase would continue for at least as long as light conditions were favorable, but rather, from February 10 to 13 the corresponding oxygen values showed a general decline. (2) An appreciable increase occurred at Station 2, but not at Station 6, correlated with the fact that water had soaked out from the flooded area in the lower part of the snow cover to surround Station 2 while not quite reaching Station 6. And (3) Numerous drainage holes were evidence that much flood-water had run into the lake, and this water was found to be, in two tests, very high in dissolved oxygen content. While the February 10 analyses showed a marked increase in oxygen under the flooded area, the stations outside this area showed much less of an increase (at Station 2) or none at all (Stations 1, 6, and 7). During most of the daylight time from February 10 to 14 there was clear sky and bright sun giving good illumination under the flooded area. During this same period there was a general reduction (of about 50%) in the oxygen content in the 0-3 inch layer within the cleared area, but concurrently there was some increase in oxygen at the stations outside the cleared area and in deeper water under the cleared area; a suggested explanation is that there was some dispersal of oxygen, by diffusion or mixing, both laterally and downward from the surface water just beneath the cleared area. It is of some practical significance that reduction of oxygen under the flooded area was only about 50 per cent during the 5 to 7 days following the flooding; for the amount of oxygen remaining on February 14 (2.81 and 1.67 at Stations 3 and 4) would be of definite value in keeping fishes alive, judging from our observations (discussed later) on Green and other lakes. The 24-hour thaw, and some rain, on February 14-15 with the resultant run-in of thaw water, was accompanied by an appreciable increase in surface oxygen in Green Lake. This was indicated by the February 16 analyses at Stations B and F and at all except one of Stations 1 to 7. At the experimental area the increase, from February 14 to 16, was greater at stations outside the flooded area than at stations within it; and this fact supports our contention that the increase in oxygen was due to run-in rather than to photosynthesis, for there was 3 to 4 inches of snow outside the cleared area to supply run-in water while there was no snow left over the cleared area. Following February 15, Green Lake remained clear of snow; and during the period of February 16 to 19 there was little thaw, and light conditions were mostly bright. Over this 3-day period (February 16-19) there was an appreciable loss (approximately 50%) of surface oxygen along the line of seven stations and at other stations on the lake, concurrent with some increase in oxygen at 3-and 4-foot (bottom) depths. Here is a second indication of a downward diffusion of oxygen, and/or a second indication that a favorable opportunity for photosynthesis did not result in a rapid build-up of dissolved oxygen. A favorable aspect, however, is that at least one p.p.m. of oxygen was retained by the lake for several days.

The considerable rain and thaw on February 21-26 was accompanied by an oxygen increase (February 27 analyses) and the thaw on March 2 to 4 and especially March 5 was accompanied by another substantial increase in oxygen. It is emphasized that following the experimental flooding and each of three thaws there was found a substantial increase in oxygen, especially in surface waters; but following two intervening periods of bright and cold weather (not thawing), favorable for photosynthesis, there was some decrease, rather than a marked increase, in dissolved oxygen.

The flooding operations at Green Lake added 3 to 4 p.p.m. of oxygen to an acre-foot of surface water. This quantity of oxygen has the potential capacity of keeping alive a very large number of fish (as will be discussed in the following paragraph). This would be especially true if, by repeated floodings on a daily or less frequent schedule, the oxygen concentration could be built up above the 3 to 4 p.p.m. level; for a greater proportion of the oxygen supply would be available to fishes at the higher concentrations. The effect of the three thaws on Green Lake in materially building up the oxygen in the surface water suggests that continual or frequent pumping and ice-flooding operations would accomplish the same end.

At the time of our flooding operation on Green Lake, probably many of the fish in the lake were dead; and we did not observe that any fish were attracted to the flooded area. But on the basis of a very theoretical calculation it can be shown that the quantity of oxygen present was enough to meet the oxygen demands of a large number of fish. In calculating the carrying capacity of a quantity of oxygen for fish life, allowance must be made for two limiting factors: firstly, part of the oxygen would be consumed by organic decomposition, and secondly, the fishes could survive only if the oxygen concentration remained above a certain level. Presumably, repeated flooding would keep the oxygen concentration level above the minimum requirements of fishes. In the case of Green Lake about 50 per cent of the 3 to 4 p.p.m. of oxygen remained for several days after the flooding. In the present theoretical calculation we are assuming that one-third of the 3 to 4 p.p.m. of oxygen in the acre-foot of surface water would be available to fishes for respiration, and that repeated flooding would keep this amount continuously available. Data compiled from the literature by Greenbank (Institute Report 853, p. 75) indicate that our warm-water game fishes would consume, at near-freezing temperatures, about 25 c.c./ kg./ hr. (25 c.c. of oxygen per kilogram of fish per hour), or 0.864 pounds of oxygen per 1,000 pounds of fish per day. One-third of the oxygen in an acre-foot of water at 3 to 4 p.p.m. is approximately 2 1/2 pounds of oxygen, or enough for 1,000 pounds of fish for 3 days. Thus, according to this rough calculation, 4 to 6 hours of pumping every 2 or 3 days would supply enough oxygen to keep alive 1,000 pounds of fish, if fish would be attracted to the area, or whatever smaller quantity of fish were present under the flooded area. Allowances for various uncertainties in the above calculation have been made on the side of safety. On the basis of the flooding experiment at Green Lake, it is our belief that this method is worthy of a large-scale attempt at preventing winterkill when such a recurrence is threatened on our lakes.

Fish Mortality

During the winter field study frequent observations were made on the reactions of fishes to oxygen deficiencies and on the occurrence of dead fish. Later, after the ice "went out" on the lakes, mortality counts were made on the dead fish windrowed along shore on seven of the lakes which had heavy kills. These counts were made as contributions to the lake population studies under the supervision of L. A. Krumholz. After these mortality counts were made, gill nets and fyke nets were fished in 16 of the winterkilled lakes to determine what fishes had survived the mortality. Various Institute staff members (including

A. S. Hazzard, W. F. Carbine, L. A. Krumholz, G. N. Washburn, and G. P. Cooper) took part in the mortality counts and netting operations. In addition to the data obtained by Institute field parties, information on the extent of winterkill throughout the state was obtained from questionnaires sent out to all state conservation officers. The officers were asked to report all instances of winterkill in their areas. Our winter field notes on mortality and reactions of fish to low oxygen are given, by lake, immediately below; and these are followed by the results of the officers' reports, mortality counts, and netting operations.

Green Lake

No evidence of fish distress or mortality was observed on February 12 and 22, but this fact is not of critical significance because we were not looking for such evidence on these initial visits. On later dates we attempted to determine whether or not fish were dying.

On February 29 the single inlet, at the southwest corner of the lake, was found to have a flow of about 50 g.p.m. near its mouth. The lower 100 yards of the stream was frozen over, and above this was open water. Many fish were found to be congregated in the lower 150 yards of the stream, above which the stream was too small for the fish present. We estimated several thousand fish in the stream including mud pickerel, bullheads (2 species), and chub suckers in about equal numbers, and a few pumpkinseed sunfish, golden shiners, and yellow perch. Through several holes cut at the mouth of the inlet, we were able to catch several bullheads with our hands (the fish were obviously in a stupor). Fish in the stream had obviously come from the lake. On January 31 the inlet was "packed" with several times as many fish as were present on the 29th. We estimated 10 to 20 thousand fish including mud pickerel, bullheads (2 species), chub suckers, golden shiners, pumpkinseed sunfish, and yellow perch in about equal numbers, and a few mud minnows. We saw no bluegills, crappies, or bass in the inlet. On the 31st., the inlet had a flow of about 50 g.p.m. through the concentration of fish. An oxygen sample at the upstream end of the concentration of fish had 7.1 p.p.m., a sample at the mouth of the inlet had 0.05 p.p.m. Most of the live fish at the mouth of the inlet were bullheads. Respiration by the fish, plus possibly some oxidation of bottom mud roiled up by the fish, was removing practically all oxygen from this 50 ~~500~~ g.p.m. flow. No fish mortality was observed among this congested population, although some dead fish may have been present under the ice near the mouth of the inlet. On February 1 the fish population in the inlet was about the same as on January 31. On February 5 the inlet contained an estimated 5,000 fish, with about the same species composition as on January 31. There were a few dozen dead fish in the inlet which may have been killed by local people dipping fish from the inlet during the past week. On February 19 the inlet was frozen over in the lower 75 yards, had a flow of 150 g.p.m., and a water temperature of 38° F. at a point 150 yards from its mouth at 10:30 A.M. No live fish could be seen in the inlet, but there were several hundred dead fish of various species. These dead fish may have been mostly mortality caused by local people dip-netting fish here the past 3 weeks. From intermittent observations we estimated that from 5,000 to 20,000 fish were so taken from the inlet during the 3 weeks past. Presumably any surviving fish had returned to the lake by February 19, for oxygen conditions were considerably improved in the lake by the thaw and rain on February 14-15. It is possible, but not known, that very few fish survived in the stream. On February 26, no live fish could be found in the inlet.

The concentration of fish in the inlet was first observed (on January 29) when oxygen in the lake was less than 1 p.p.m. How long fish had been in the inlet is not known, but it is known that many thousands of fish (of a variety of species) came from the lake into the inlet (January 29 to 31) while oxygen in the lake was less than 1 p.p.m. The reduction in the stream population from February 1 to 5 must be attributed to netters or other mortality; for the lake was extremely low in oxygen (not over 0.3 p.p.m.) on February 5 and 7, and it seems doubtful that the fish could have returned to, and survived in the lake.

On Green Lake itself, some observations on mortality were made at holes cut in the ice. Four holes (each 2 feet X 2 feet) were opened at scattered locations on January 29. In one hole, near the center of the lake, several live fish came to the surface within an hour: four adult bluegills and several bullheads(_A. natalis_), young bluegills, sunfish, and yellow perch. These fish were obviously distressed. Dissolved oxygen was 0.36 p.p.m. at a depth of 6 inches and 0.0 p.p.m. at the bottom (6 feet). On January 31, the holes were reopened, and there were five live (but distressed) calico bass (4"-6") at one hole, but no dead fish. The oxygen was 0.78 p.p.m. at the surface at this hole. On February 1, at two of the holes there were many bullheads, mostly dead, and a single live golden shiner, but no other fish. Surface oxygen, at one hole, was 0.83 p.p.m. On this date, using a canvass cover to facilitate observations, we examined the lake bottom at these two holes and at four other small ones, and saw one dead bullhead and several dozen other dead fish (mostly centrarchids) on the bottom. On February 5, two of the large holes were kept open, at which we saw several dead bullheads, one live one, and no other fish. Oxygen was 0.1 p.p.m. at the surface.

During the period from February 7 to March 5 we cut new holes or reopened old holes about 50 times in collecting water samples, but did not see any live fish at any of these holes.

On February 26 we found on Green Lake about 15 areas where it was possible to see clearly through the ice. Many dead fish could be seen lying against the under surface of the ice. The fish were mostly bluegills, bass, perch, some chub suckers, and a few bullheads and black crappies. Some of the bass were estimated at 2 to 4 pounds in weight. Roughly 50 per cent of the fish were less than 4 inches long. The 15 clear areas averaged about 15 by 15 feet in size, and all contained dead fish, except for areas over very shallow water.

Our observations at Green Lake did not give a good idea as to the point in oxygen depletion at which most of the fish mortality took place. We do know that at least a few bluegills, black crappies, shiners, and bullheads lived in the lake for several days after the oxygen got down to less than 1 p.p.m.; and that several thousand mud pickerel, bullheads, sunfish, perch, golden shiners, and chub suckers had survived for a few days near the mouth of the inlet in less than 1 p.p.m. of oxygen. The bluegills, bass, and black crappies were not congregated in the inlet at the time of our observations; and the few bluegills and crappies which we saw in the lake on January 29 and 31 probably represented the last survivors of these species.

First Sister Lake

At this lake we had a fairly good opportunity to determine the point in oxygen depletion at which the fish became distressed by observations at a hole (12 feet in diameter) in the ice kept open by a wind rotor air pump. We also had an opportunity to evaluate the effect of this pump in supplying oxygen to the lake. There were no signs of fish mortality or of fish in distress on January 12 and 29, on which dates the air hole was open; surface oxygen values were 2.90 and 2.28 p.p.m. respectively at the center of the lake and 1.09 p.p.m. at the air hole on January 29. On February 5, when surface oxygen was 0.42 p.p.m. at the center of the lake and 0.21 p.p.m. at the open air hole, there were several hundred golden shiners, a few young bluegills and chub suckers, and 6 adult mud pickerel seen near the surface at the air hole; these fish were distressed and crowding near the surface but they were all alive and still sufficiently wary to be readily scared away. On February 14 the surface oxygen was 0.20 p.p.m. at the center of the lake and 0.07 p.p.m. at the open air hole, and a water sample collected from the surface film at the air hole contained 0.32 p.p.m. On this date there were an estimated 10 to 20 thousand fish milling around at the surface of the air hole. These fish were distressed; they were still live enough to be freightened away; but, if not further disturbed, they returned to the air hole within a few minutes. These fish were mostly golden shiners and bullheads, a few chub suckers, sunfish, crappies, mud pickerel, and mud minnows, and one northern pike about 14 inches long. Most of the fish were 2 to 5 inches long. About a dozen dead golden shiners and bullheads were at the surface. We could not see the bottom of the pond at the air hole, and therefore had no idea as to the number of dead fish there, if any. On February 16, after the 24-hour thaw on the 15th, with surface oxygen 3.0 p.p.m. (this high oxygen value probably represented a pocket of run-in water of very limited extent) at the center of the lake and 0.74 p.p.m. at the air hole, we still found many thousands of fish at the open air hole. These were all small golden shiners, and they were not so distressed as on February 14. On February 27, with surface oxygen down again to 0.39 p.p.m. at the center of the lake and at 0.74 p.p.m. at the air hole, we saw several dozen dead shiners and chub suckers at the surface of the air hole, but no live fish here. On March 5, after a considerable thaw and run-in, and with surface oxygen at the center of the lake up to 2.40 p.p.m., we could not get within 25 feet of the air hole for an examination, but there were no signs of live fish at the surface of this opening. We know for First Sister Lake that many thousands of fish of several species (listed above) lived for several days in less than 1 p.p.m. of oxygen.

The air rotor pump at First Sister was found to be working on the occasions of 6 of the 8 visits to the lake. In other words it was operating most of the time during the interval of the present study. The pump requires only a slight wind to keep it working. Our oxygen tests (see Table I) indicated that the pump was not accomplishing its purpose of supplying oxygen and preventing winterkill. The value of the pump might be greatly increased if the air were expelled from many fine holes. With the present air vent the air rises to the surface all at one point and in the form of large bubbles which afford little opportunity for oxygen absorption; another bad feature is that the up-welling of water currents, caused by the rising air, stirs up the bottom mud. The decomposition of this mud might take considerable oxygen from the water.

Sugarloaf Lake

On March 5 about a dozen dead fish were seen through the ice; conditions for observations were poor so that this record is merely an indication of some kill in this lake. Several reports by ice fishermen were that they had seen no fish around their fishing holes.

Batteese Lake

We received no reports of fish mortality in personal interviews with ice fishermen on our three visits to this lake. On February 5, one of these fishermen reported that fish were acting quite sluggish however. He had speared one *Amia*, and reported seeing one bass (about 5 lbs.) both within 3 feet of the surface. He further reported seeing, in his shanty, numerous small fish all within 3 feet of the surface. On February 13, when surface and 5-foot oxygen samples were down to 0.05 to 0.64 p.p.m., fishermen reported no dead fish, and in one shanty in about 10 minutes we saw a dozen half-grown bluegills pass through the hole.

Grass Lake

On February 14, when oxygen was 0.69 p.p.m. at the surface and 0.64 p.p.m. at 4 feet (bottom), we found 4 young bluegills still alive within a fishing hole (thinly frozen over) in a shanty. On February 27 we had a fairly good opportunity to see any dead fish which might be lying against the under surface of the ice. We counted several dozen small fish (centrarchids and perch) and 10 larger fish (perch or bass) in 15 minutes walking over the ice. These observations indicated a light winterkill, at least, in this lake.

Goose Lake

On February 27, a local garageman reported seeing many dead perch and a few bass against the ice during the last few days.

Cassidy Lake

On February 19, we received a report that fishermen yesterday found many dead fish when cutting holes in the ice for fishing.

The winterkill questionnaire (Figure 3) was sent out to the conservation officers prior to the spring break-up of ice on the lakes so that the officers had an opportunity to record any dead fish observed in lakes in their counties. The response from the officers was judged to be generally good, although some instances of fish mortality in a few counties were not reported, presumably because many officers were being reassigned at the time from one county to another. All winterkilled lakes reported by conservation officers, plus all such lakes in the Washtenaw-Jackson area which were being observed by Institute staff members, are listed in Table 3. The table gives, for each lake, its location, area, extent of the fish mortality, the conservation officer or other individual who reported the mortality, and the principal species of fish which were affected. Of the 54 lakes listed in the table, the mortality was reported to be light in three (St. Helen, Fisk, and Grass). In the remaining 51 lakes, having a combined area of 4,183 acres, the mortality was reported to have been mostly heavy or very heavy. Almost all of these lakes were in the southern half of the lower peninsula. It seems probable that there were at least a dozen additional lakes in the southern part of the state which had a winterkill that was not reported.

The lakes which winterkilled fall into one definite type. They are shallow lakes, mostly less than 10 feet deep and very few over 20 feet, mostly with muddy bottom and abundant aquatic vegetation, and commonly with marshy shores. The fact that 6 of the 54 lakes are named Mud Lake is pertinent. The fish species which were commonly recorded in the mortality reports were, naturally, the species which are commonly adapted to this type of lake: largemouth bass, bluegills, sunfish, yellow perch, northern pike, mud pickerel, bullheads, and golden shiners. Bluegills and largemouth bass were most consistently reported as having been killed in large numbers.

Immediately after the lakes cleared of ice, counts were made on windrowed dead fish on seven lakes. The technique used was to identify and count the fish in short and representative, measured sections of the shoreline, and to estimate the total mortality on the basis of these counts. A summary of these counts on the seven lakes (in Washtenaw, Jackson, and Oakland counties) is given in Table 4. It should be emphasized that these are minimum, and presumably partial values for the total fish mortality in these lakes, for any dead fish which remained on the lake bottom or any fish (especially small ones) which might have been ground up by ice and wave action would not be included in these totals. On most lakes relatively very few small fish were seen along shore. We do know, however, that in Green Lake many small fish were killed for we saw them lying against the ice; and it is reasonable to assume that this condition existed in most of the other lakes. These counts show 483 fish per acre for the 912 acres in these seven lakes. Assuming the figures for these 7 lakes to be representative of the kill in all 51 lakes of 4,183 acres, the total mortality would be about 2,000,000 fish as a minimum figure. In the seven lakes, one-third of all fish were legal-sized game fish.

On the seven lakes where mortality counts were made, the 440,331 fish in the estimated total kill included the following:

265,402	bluegills
43,409	pumpkinseed sunfish
32,490	bullheads
24,432	lake chub suckers
23,103	yellow perch
22,315	largemouth bass
8,995	warmouth bass
7,332	black crappies
3,159	mud pickerel
2,322	northern pike
720	green sunfish
521	bowfins
150	golden shiners
5,981	all other fish

Of the bluegills, 165,000 were on Batteese Lake; but the bluegill was the predominant species in the kill also on most other lakes. Many of the sunfish, perch and bullheads were small and/or occurred in only a few lakes. A large proportion of the largemouth bass and northern pike were large fish, and they represented a greater loss to anglers than their smaller numbers would indicate at first glance. The bluegills and bass suffered the greatest loss of catchable fish in these seven lakes, as well as in the majority of the lakes reported on by the conservation officers.

During the period from April 9 to May 21 gill and fyke netting was done by Institute staff members in 16 of the lakes listed in Table 3. This netting was done to determine what fishes survived in the lakes. Gill nets of various mesh sizes were used in each lake to check on fish of different sizes. The 16 lakes which were netted are believed to be fairly representative of the 51 winterkilled lakes as a group, in indicating the extent of survival of different species of fish. The results of the netting operations are given in Table 5. The most striking fact which this netting demonstrated is that at least some fish survived in probably every lake which winterkilled. The nets took fish in all of the 16 lakes except Swifts' Lake, and it seems probable that some fish would have been found in this lake if more than the one 125-foot experimental gill net had been used in the one-night set. The nets took large numbers of fish in many of these lakes, especially Green, Batteese, Goose, Huntoon, Evans, Twin, and Dustin, in which the total numbers caught were about what one might expect to take following a normal winter. In other lakes the total catch was low, indicating an extensive decimation of the total population, examples being Pettits and Long lakes and Mud Lake in Crystal Township. The species composition of the net catches was markedly different from that of the winterkill, judging from all available data. The conclusion is that the kill was to a considerable extent selective, killing off a much greater proportion of some species than of others, as indicated by the following:

Number in mortality counts, or as reported by conservation officers	Species	Number taken by subsequent netting in 16 lakes
very many	bluegills	very few
very many	pumpkinseed sunfish	few
many	black crappies	few
many	largemouth bass	very few
many	northern pike	many
many	yellow perch	very many
many	bullheads	very many
many	warmouth bass	very few
few	mud pickerel	few
many	lake chub suckers	very many
few	golden shiners	very many
few	bowfin	few

The data from which the above summary has been made are given in Tables 4 and 5.

Since the winterkill was highly selective in destroying a large percentage of the game and pan fish and leaving mostly rough fish, the lakes were left in a less satisfactory condition. The now abundant rough fish have the opportunity of taking over most of the area, and probably retarding the recovery of the game species.

Fish Mortality Related to Low Dissolved Oxygen

Having made winter oxygen analyses on several lakes which suffered a heavy kill, and on lakes which had little or no kill, and having made mortality counts and subsequent nettings on several of these same lakes, we can draw some conclusions on the degree of oxygen depletion which is necessary to cause a heavy winterkill and the extent to which some species can tolerate lower dissolved oxygen values than can others. The conclusions become obvious in the following summary for several of the lakes cited previously in this report:

Lake	Lowest point, during winter, in dissolved oxygen in upper 4 feet of water, approximately:	Effect on fish
Cavenaugh	9.21 to 3.55 p.p.m.	No kill
Four Mile	7.39 to 2.61 (probably down to 4.0 to 2.0 p.p.m.)	No kill
Mill	4.09 to 3.0 p.p.m.	No kill
Sugarloaf	1.82 to 0.74 p.p.m.	Practically no kill
Cassidy	1.13 to 0.74 (probably 0.8 to 0.7 p.p.m.)	Very light kill, if any
Grass	0.69 to 0.64 p.p.m.	Very light kill, even of bass and bluegills
Batteese	0.64 to 0.54 p.p.m.	Very heavy kill of bluegills and bass, but some survived; light kill on other species
First Sister	0.32 to 0.2	Possibly not a heavy kill of golden shiners, chub suckers, mud pickerel
Goose	0.47 to 0.05 (probably some lower)	Heavy but partial kill of largemouth bass and bluegills; good survival of perch, pickerel, and chub suckers.
Green	0.3 to 0.2 to 0.1	Possibly complete kill of bass and bluegills, good survival of perch, bullheads, golden shiners, and chub suckers
Merkle	0.21 to 0.0	Probably complete kill of bass and bluegills; some survival of bullheads and golden shiners

We conclude from the above that a heavy winterkill in these lakes did not occur except where the dissolved oxygen was reduced to considerably less than 1.0 p.p.m. in all parts of the lake. The critical point seemed to be in the vicinity of 0.7 to 0.6 p.p.m., as indicated by the difference between Grass and Batteese lakes. Below 0.5 p.p.m. of oxygen there was a very heavy mortality of most fish, and especially of bass and bluegills. Where the oxygen got down to 0.3 and less (in Green and Merkle), there was possibly no survival of bass and bluegills; but there was still a considerable survival of yellow perch, bullheads, golden shiners, and chub suckers. It would seem that a complete extermination of some of these species by winterkill in these Michigan lakes is virtually impossible because of their tolerance to very low oxygen values coupled with the improbability of complete oxygen depletion throughout all parts of a lake. Tributary streams, springs, ground water seepage, and ice fractures probably make a complete oxygen depletion impossible.

Our figures on the oxygen thresholds at near-freezing temperatures of these common lake fishes are notably lower than the values given by Moore[5] for the same species. Moore, working in Minnesota, used wire cages to hold fish at a certain depth in lakes at a desired and known oxygen concentration. He used several of our common lake species, and he held his fish at the desired depth for a 48-hour period. All rock bass, largemouth bass, and northern pike died at oxygen concentrations of 2.3 p.p.m. or less, while some of each of these three species survived for the 48-hour period in oxygen concentrations above 2.3 p.p.m. The corresponding oxygen thresholds found by Moore for other species were: yellow perch, 1.5 p.p.m.; black crappies, 1.4; pumpkinseed

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[5] Moore, Walter G. 1942. Field studies on the oxygen requirements of certain fresh-water fishes. Ecology. Vol. 23, No. 3, pp. 319-329.

sunfish, 0.9; bluegill, 0.8; black bullhead, 0.3; and golden shiner, 0.0. Moore's general conclusions were that all species survived at oxygen values above 3 p.p.m., a few of the least tolerant species succumbed at 2 to 3 p.p.m., 1 to 2 p.p.m. was fatal to most species, and oxygen values below 1 p.p.m. were fatal to all species except for a few individual bullheads. Our figures for Michigan lakes would set the oxygen thresholds for most of the lake species somewhat lower than the figures given by Moore. A suggested possible explanation for this difference is that Moore's fishes might have been transferred into the experimental lakes from water which was relatively high in dissolved oxygen, while in the Michigan lakes the fish had been in the presence of a slowly diminishing oxygen content and may therefore have been able to adjust their metabolism to a lower oxygen threshold.

Summary

A heavy winter mortality of fishes occurred in 51 recorded lakes in the state during the winter of 1944-45. These lakes were mostly in the southern half of the lower peninsula, and they were the shallow type of lake with mud bottom, abundant vegetation, and frequently with marshy shores.

The 51 lakes had a combined area of 4,183 acres, and a mortality estimated to be at least 2,000,000 fish of which about one-third were legal-sized game fish. In spite of the heavy mortality, subsequent netting showed that many of the lakes still had abundant fish populations, and presumably all of the lakes had at least some fish left.

The kill was to a considerable extent selective for species. It greatly decimated the bass, bluegills, and other centrarchids; was only partially effective on the perch, pike and bullheads; and left very large numbers of bullheads and golden shiners.

Of the lakes on which water analyses were made, the only lakes which winterkilled were the ones in which the dissolved oxygen got down to about 0.8 to 0.7 p.p.m. or less.

An attempt to alleviate winterkill conditions on Green Lake by pumping lake water onto the ice and wetting down the snow cover was, to a limited extent, successful; or at least it demonstrated that it would be worthwhile to apply this method to one or two lakes in a concerted effort, if and when a probable winterkill is likely in the future. It was our observation that fishermen reported a sharp decline and cessation of fish biting at about the time when a particular lake was approaching the critical low oxygen stage; and this would be a good index as to the time at which pumping operations should be started, i.e., about the time fish stop biting on lakes which are apt to winter-kill.

Recommendations

Recommendations for restocking certain of these winterkilled lakes have been made by correspondence to the Fish Division in Lansing.

INSTITUTE FOR FISHERIES RESEARCH

by G. P. Cooper and G. N. Washburn

Approved by: A. S. Hazzard

Typed by: M. Klaphaak

Table 1

Dissolved oxygen in lakes in the Washtenaw-Jackson area, at different water depths, winter of 1944-45. For locations of stations on the lakes, see text.

Name of lake	Depth of sample, below ice	Jan. 12	Jan. 22	Jan. 29	Jan. 31	Feb. 1	Feb. 5	Feb. 12	Feb. 13	Feb. 14	Feb. 16	Feb. 19	Feb. 27	Feb. 28	Mar. 5
Sugarloaf	0-3"	...	...	...	...	...	...	...	...	...	...	1.82	...	...	...
	6"-1'	5.41	7.90	4.42	...	...	2.55	1.82	...	...	...	0.74	4.73	...	8.30
	2'	...	...	...	...	...	...	...	...	...	...	...	...	...	0.77
	4'	...	...	...	...	...	0.83	0.74	...	...	...	0.34	0.39	...	0.82
	8'	...	2.34	1.45	...	...	0.36	0.10	...	...	...	0.05	0.05	...	0.10
	14'	2.20	2.13	0.88	...	...	0.0	0.0	...	...	...	0.0	0.0	...	0.0
First Sister (center of lake)	6"-1'	2.90	2.39	2.28	...	...	0.42	...	...	0.20	3.00	...	0.39	...	2.40
	2'	...	...	...	...	...	...	...	...	...	...	...	...	...	0.58
	5'	...	1.30	1.02	...	...	0.36	...	...	0.10	...	...	0.10	...	0.14
	10'	...	0.21	0.47	...	...	0.16	...	...	0.05	...	...	0.0	...	0.0
	17'	0.67	0.0	0.05	...	...	0.0	...	...	0.0	...	...	0.0		0.0
First Sister (at "air hole")	Surface film	...	...	...	...	...	...	...	...	0.32	...	...	...	...	...
	6"-1'	...	1.87	1.09	...	...	0.21	...	...	0.07	0.74	...	0.74	...	...
	5'	...	...	0.99	...	...	0.16	...	...	0.07	...	...	0.34	...	...
	8'	...	1.04	0.62	...	...	0.10	...	...	0.07	...	...	0.05	...	...
Batteese	6"-1'	7.84	...	...	...	...	1.61	...	0.05 & 0.54 ✓	...	...	...	...	...	...
	5'	...	...	...	...	...	1.40	...	0.64	...	...	...	...	...	...
	10'	...	...	...	...	...	0.26	...	0.0	...	...	...	...	...	...
	13'	2.27	...	...	...	...	...	...	...	...	...	...	...	...	...
	16'	...	...	...	...	...	0.0	...	0.0	...	...	...	...	...	...
Grass	6"-1'	...	...	...	...	...	2.70	...	...	0.69	...	...	1.38	...	...
	3'	...	...	...	...	...	1.61	...	...	...	...	...	0.0	...	...
	4'	...	...	...	...	...	...	...	...	0.64	...	...	...	...	...

A 24-hour thaw on Feb. 15; lakes cleared of snow, and much run-in of water. Further thaws and run-in on Feb. 21-23 and Mar. 2-5.

✓ Analyses made at two stations in the same general area on the lake.

(Table continued on next page.)

Table 1 (Continued)

Dissolved oxygen in lakes in the Washtenaw-Jackson area, at different water depths, winter of 1944-45. For locations of stations on the lakes, see text.

Name of lake	Depth of sample, below ice	Jan. 12	Jan. 22	Jan. 29	Jan. 31	Feb. 1	Feb. 5	Feb. 12	Feb. 13	Feb. 14	Feb. 16	Feb. 19	Feb. 27	Feb. 28	Mar. 5
Goose	6"-1'	...	...	...	...	...	0.47	...	...	...	...	...	6.06	...	6.48
	3'	...	...	...	...	...	0.05	...	...	...	...	...	2.27	...	3.60
Merkle	6"-1'	...	...	...	...	...	0.21	...	...	...	...	...	...	...	...
	4'	...	...	...	...	...	0.0	...	...	...	...	...	...	...	...
Mud	6"-1'	...	...	...	...	1.77 & 1.82†	...	...	...	...	...	...	...	...	...
	3'	...	...	...	...	0.31	...	...	...	...	...	...	...	...	...
Mill	6"-1'	...	...	...	...	...	...	4.09	...	...	...	...	...	...	...
	4'	...	...	...	...	...	...	3.00	...	...	...	...	...	...	...
	8'	...	...	...	...	...	...	0.0	...	...	...	...	...	...	...
Cavenaugh	6"-1'	...	...	...	...	...	...	...	...	9.21	...	...	...	...	...
	5'	...	...	...	...	...	...	...	...	3.55	...	...	...	...	...
	10'	...	...	...	...	...	...	...	...	1.18	...	...	...	...	...
	20'	...	...	...	...	...	...	...	...	0.0	...	...	...	...	...
Four Mile	6"-1'	...	...	...	...	...	...	...	...	...	7.39	...	...	...	...
	2'	...	...	...	...	...	...	...	...	...	2.61	...	...	...	...
	14'	...	...	...	...	...	...	...	...	...	0.84	...	...	...	...
Cassidy	0-3"	...	...	...	...	...	...	...	...	...	...	1.13	...	...	...
	2'	...	...	...	...	...	...	...	...	...	...	0.74	...	...	...
	5'	...	...	...	...	...	...	...	...	...	...	0.79	...	...	...
Big Silver	6"-1'	...	...	...	13.6	...	...	...	...	...	...	...	...	...	...
	10'	...	...	...	2.3	...	...	...	...	...	...	...	...	...	...
Deep	6"-1'	...	...	...	...	...	...	...	...	...	...	...	...	10.79	...
	10'	...	...	...	...	...	...	...	...	...	...	...	...	5.86	...
	20'	...	...	...	...	...	...	...	...	...	...	...	...	5.64	...
	30'	...	...	...	...	...	...	...	...	...	...	...	...	5.61	...
	40'	...	...	...	...	...	...	...	...	...	...	...	...	4.53	...
	44'	...	...	...	...	...	...	...	...	...	...	...	...	3.30	...

A 24-hour thaw on Feb. 15. Lakes cleared of snow, and much run-in of water. Further thaws and run-in on Feb. 21-23 and Mar. 2-5.

† Analyses made at two stations in the same general area on the lake.

Table 2

Dissolved oxygen in Green Lake at different water depths and stations, winter of 1944-45.

Stations A to G were scattered over the area of the lake; Stations 1 to 7 were consecutively along a 550-foot line which extended across, and beyond the limits of a one-acre flooded and cleared area (see text).

Station	Depth of sample, below ice	Jan. 12	Jan. 22	Jan. 29	Jan. 31	Feb. 1	Feb. 5	Feb. 7	Area flooded and cleared of snow Feb. 7 and 9	Feb. 10	Feb. 12	Feb. 13	Feb. 14	On Feb. 15, a 24-hour thaw, lake cleared, much run-in of water. Much thaw and run-in of Feb. 21 to 23 and March 3 to 5	Feb. 16	Feb. 19	Feb. 27	Mar. 5
1	0-3"	...	...	...	...	...	...	...		0.0	0.10	0.15	0.20		2.36	1.33	3.69	5.38
	6"-1'	...	...	...	...	...	...	...		...	...	0.10	...		...	0.69	...	...
	3'	...	...	...	...	...	...	...		0.0	0.0	0.0	0.0		0.0	0.49	0.25	1.01
2	0-3"	...	...	...	...	...	...	...		0.73	0.30	0.20	0.64		3.25	1.38	...	4.99
	6"-1'	...	...	...	...	...	...	0.21		...	...	0.05	...		...	0.44	...	...
	3'	...	...	...	...	...	...	0.10		0.0	0.0	0.0	0.0		0.1	0.34	...	0.19
3	0-3"	...	...	...	...	...	...	...		3.80	1.77	1.97	2.81		0.64	0.54	...	4.27
	6"-1'	...	...	...	...	...	...	...		...	...	0.59	...		...	0.44	...	...
	4'	...	...	...	...	...	...	...		0.0	0.20	0.05	0.23		0.0	0.15	...	0.0
4	0-3"	...	...	...	...	...	...	...		3.22	1.18	2.17	1.67		2.41	0.49	3.74	5.86
	6"-1'	...	...	...	...	...	...	0.16		...	...	0.25	...		...	0.54	...	...
	2'	...	...	...	...	...	...	...		1.77	0.34	0.10	0.52		1.48	0.15	0.15	0.96
	3'	...	...	...	...	...	...	0.10		0.21	0.20	0.0	0.15		0.25	0.15	0.0	0.29
4a	0-3"	...	...	...	...	...	...	...		...	...	0.89	...		...	...	...	...
	6"-1'	...	...	...	...	...	...	0.21		...	...	...	...		...	...	...	...
	3'	...	...	...	...	...	...	0.0		...	...	...	...		...	...	...	...
5	0-3"	...	...	...	...	...	...	...		4.00	0.34	0.89	0.49		0.94	0.94	...	3.31
	6"-1'	...	...	...	...	...	...	...		...	...	0.25	...		...	0.64	...	...
	2'	...	...	...	...	...	...	...		...	...	...	...		...	...	...	1.20
	4'	...	...	...	...	...	...	...		0.0	0.05	0.0	0.0		0.05	0.15	...	0.0
6	0-3"	...	...	...	...	...	...	...		0.10	0.10	0.25	0.25		1.08	1.38	...	3.89
	6"-1'	...	...	...	...	...	...	0.31		...	...	0.17	...		...	0.39	...	...
	3'	...	...	...	...	...	...	0.0		...	...	...	...		...	...	...	...
	4'	...	...	...	...	...	...	...		0.0	0.0	0.0	0.0		0.0	0.05	...	0.0
7	0-3"	...	...	...	...	...	...	...		0.0	0.05	0.34	0.15		0.64	0.02	2.27	5.38
	6"-1'	...	...	...	...	...	...	...		...	...	0.05	...		...	0.0	...	...
	4'	...	...	...	...	...	...	...		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0

(Table continued on next page)

Table 2 (Continued)

Dissolved oxygen in Green Lake at different water depths and stations, winter of 1944-45.

Stations A to G were scattered over the area of the lake; Stations 1 to 7 were consecutively along a 550-foot line which extended across, and beyond the limits of a one-acre flooded and cleared area (see text).

Station	Depth of sample, below ice	Jan. 12	Jan. 22	Jan. 29	Jan. 31	Feb. 1	Feb. 5	Feb. 7	Feb. 10	Feb. 12	Feb. 13	Feb. 14	Feb. 16	Feb. 19	Feb. 27	Mar. 5
A	6"-1'	...	...	...	0.10	...	...	...	...	...	...	...	...	...	...	...
B	0-3"	...	...	...	...	...	...	...	...	...	0.10	...	2.27	1.08	...	3.65
	6"-1'	2.20	...	0.36	0.78	...	...	...	...	...	0.10	...	...	0.10	...	...
	2'	...	...	...	...	...	...	...	...	...	...	...	0.0	0.05	...	0.43
	5'	1.33	...	...	...	...	...	...	...	...	...	...	...	....	...	...
	6'	...	...	0.0	0.0	...	...	...	...	...	...	...	0.0	0.0	...	0.0
C	6"-1'	...	...	...	0.05	...	...	...	...	...	...	...	...	...	...	...
D	6"-1'	...	...	...	0.16	...	...	...	...	...	...	...	...	...	...	...
E	6"-1'	...	...	...	0.26	...	...	...	...	...	...	...	...	...	...	...
F	0-3"	...	...	...	0.47	...	...	...	...	...	...	...	0.15 & 1.63*	0.20 & 0.84*	1.63	2.11
	6"-1'	...	...	...	...	...	...	...	...	...	0.03	...	...	0.07 & 0.15*	...	...
	2'	...	...	...	...	...	...	...	...	...	...	...	0.05	0.39 & 0.54*	0.05	0.34
G	6"-1'	4.78	0.94	...	0.36	0.83	0.10	...	...	...	...	...	...	...	...	...
	3'	...	...	...	0.75	0.68	0.05	...	...	...	...	...	...	...	...	...
	5'	...	0.52	...	0.31	...	0.0	...	...	...	...	...	...	...	...	...
	6'	...	0.16	...	0.10	...	...	...	...	...	...	...	...	...	...	...
	7.5'	1.10	...	...	...	...	0.0	...	...	...	...	...	...	...	...	...
Mouth of Inlet		...	...	0.10	0.05	...	...	...	...	...	...	...	...	...	...	...
75 yds. up Inlet		...	...	...	...	...	1.92	...	...	...	...	...	...	...	...	...
150 yds. up Inlet		...	...	...	7.12	...	...	...	...	...	...	...	...	...	...	...

On Feb. 15, a 24-hour thaw, lake cleared, much run-in of water. Much thaw and run-in of Feb. 21 to 23 and March 3 to 5

*At two stations about 8 feet apart.

Table 3

Lakes Reported or Observed to have had a Winterkill in 1944-45

Abbreviations for fish: Bg.=bluegill, Lmb.= largemouth bass, Ps.=pumpkinseed sunfish, Yp.= yellow perch, C.=black crappie, Np.=northern pike, Mp.=mud pickerel, Wb.=warmouth bass, Rb.=rock bass, Bh.=bullheads, Ca.=carp, Gs.=golden shiner, Cs. =lake chub sucker Bf.=bowfin, S.= Common sucker

Dist. No.	County	Name of lake	Town	Range	Section	Township	Area, acres*	Extent of winterkill	Reported by	Species killed, as reported, or observed by I.F.R.
4	Wexford	Long	22 N.	9 W.	2,3,11	Harring	200*	Heavy	Rettig	S., Lmb., C., Bg., Yp.
5	Roscommon	Mud	22 N.	2 W.	4,5,8,9	Backus	460*	Fairly heavy	Luhrs, I.F.R.	Bh., Np., Bg., Ps., Yp., Bf., etc.
5	"	St. Helen	23 N.	1,2 W.	20,21 etc.	Richfield	2,500	Light	Luhrs	Yp., Ps., Bg.
5	Ogemaw	Jenkins	23 N.	4 E.	23,24	Hill	25*	Moderate	Baird	Bg., Yp., Ca., Np.
7	Newaygo	Pettits	12 N.	11,12 W.	19,30,24	Croton, Brooks	169	Very heavy	Cline	Bg., Lmb., Yp., Np.
7	"	Atodd (Blue)	16 N.	13 W.	31	Lilley	60*	Very heavy	Robinson	Bg., Lmb., Yp., Np.
8	Ottawa	Eastman Bayou	7 N.	14 W.	9,10	Allendale	25*	Heavy	Forry	Bg., Lmb., C., Ca., Bf., Np.
8	"	Jubb Bayou	8 N.	15 W.	35	Crockery	35*	Heavy	Forry	Bg.
8	"	Fennessy	7 N.	13 W.	36	Tallmadge	35*	Very heavy	Forry	Lmb., Bg., Ps., Yp.
8	Kent	Giddings	10 N.	11 W.	1	Solon	35*	Heavy ?	Buzzard	Bg., Lmb.
8	"	Helena	10 N.	10 W.	9	Nelson	18*	Heavy	Buzzard	Bg., Lmb., Bh., C.
8	Montcalm	Duck	10 N.	5 W.	10,11,15	Crystal	306	Very heavy	Bigelow, I.F.R.	Bg., Yp., Lmb., C., Np., Bh.
8	"	Mud	10 N.	5 W.	8,9	Crystal	127	Moderate	Bigelow, I.F.R.	Lmb., Bg., Rb., Bf., Ps., Bh., etc.
8	"	Mud	10 N.	6 W.	23,24	Evergreen	54*	Moderate	Bigelow, I.F.R.	Bg., Ps., Lmb., Yp., C., Np., Bh., etc.
8	"	Nelson	10 N.	7 W.	3,4	Sidney	17*	Very heavy	Bigelow, I.F.R.	Bg., Lmb.
8	"	Pickerel	12 N.	8 W.	20,29,30	Cato	20*	Very heavy	Bigelow	Bg., Lmb., Np., C., Bh., Yp.
8	"	Hisington	10 N.	6 W.	30,31	Evergreen	16*	Moderate	Bigelow, I.F.R.	Bg., C., Ps., Np., Lmb., Bh
8	"	Horseshoe	9 N.	7 W.	36	Fairplain	19*	Heavy ?	Bigelow	Bg., Lmb., Np.
9	Allegan	Mud	1 N.	14 W.	10	Cheshire	8*	Heavy	Mr. Rowe	?
9	Van Buren	Fisk	2 S.	15 W.	26	Arlington	32*	Light	Taack	Bg., Lmb., Yp
9	Kalamazoo	Dustin	2 S.	12 W.	20	Oshtemo	35*	Very heavy	Winey	Bg., Ps., Yp., Lmb., Bh
9	"	Twin Lakes	1,2 S.	11,12 W.	1,6,31,36	Alamo	185*	Heavy	Winey	Bg., Ps., Bh., Lmb.
9	"	Bonnie Castle	2 S.	12 W.	16,21	Oshtemo	50*	Very heavy	Winey	Bh., Bg., Ps., Lmb.
9	Berrien	Murphy	6 S.	17 W.	14,23	Berrien	28*	?	Austin	Lmb., Bg.
9	Cass	Fox	6 S.	13 W.	26	Newberg	73*	Heavy	Local resident	Yp., Mp., Ps., Lmb.
9	"	Copley	5 S.	14 W.	25	Volinia	31	Heavy	Local resident	?
9	St. Joseph	Evans	6 S.	10 W.	21,28	Nottawa	85*	Heavy	Fish	Yp., Lmb., Bg., Ps., Bh.
10	Barry	Lower Crooked	1 N.	10 W.	11,15, etc.	Prairieville	350*	Heavy	Sumner	Bg., Ps., Yp., Lmb., Bh.
10	"	Loomis	2 N.	9,10 W.	18,13	Hope, Rangeville	20*	Heavy	Fortney	Bg., Lmb., Yp.
10	"	Bass	1 N.	8 W.	16	Johnstown	8*	Heavy ?	Sumner	Bg., Lmb., Yp., Bh.
10	"	Hathaway	3 N.	9 W.	4,5	Rutland	14*	Heavy	Sumner	Yp., Bg.
10	"	Gillespie (Glasdy)	1 N.	9 W.	7	Barry	45*	Heavy ?	Sumner	Yp., Bh.
10	"	Shallow	2 N.	9 W.	27,34	Hope	30*	Very heavy	Sumner	Yp., Bh., Bf., Gs., Bg., Lmb.

*Area figures marked by an asterisk are based on measurements of lake outlines given on county maps, and are assumed to be only approximate values.

(Table continued on next page)

Table 3 (Continued)

Lakes Reported or Observed to have had a Winterkill in 1944-45

Abbreviations for fish: Bg.=bluegill, Lmb.=largemouth bass, Ps.=pumpkinseed sunfish, Yp.=yellow perch, C.=black crappie, Np.=northern pike, Mp.=mud pickerel, Wb.=warmouth bass, Rb.=rock bass, Bh.=bullheads, Ca.=carp, Gs.=golden shiner, Cs.=lake chub sucker, Bf.=bowfin, S.=Common sucker

Dist. No.	County	Name of lake	Town	Range	Section	Township	Area, acres*	Extent of winterkill	Reported by	Species killed, as reported, or observed by I.F.R.
10	Ingham	Jones	4 N.	2 W.	4,5	Lansing	13*	Heavy ?	Gouin	C., Gs., Bg., Ps.
10	Calhoun	Cedar	3 S.	6 W.	15	Fredonia	150*	Very heavy	Mr. Seaman	Bg., Lmb.
10	Jackson	Merkle	1 S.	2 E.	14,15	Waterloo	88.5	Very heavy	I.F.R.	Bg., Cs., Ps., Wb., Np., Lmb., etc.
10	"	Batteese	1 S.	1 E.	9	Henrietta	100*	Very heavy	I.F.R.	Bg., Wb., Ps., Lmb., etc.
10	"	Goose	2 S.	1,2 E.	24,25,19,30	Leoni, Grass Lake	425*	Heavy	I.F.R.	Bg., Lmb., Cs., Ps., Yp., etc.
10	"	Grass	2 S.	2 E.	28,29,32	Grass Lake	360*	Very light	I.F.R.	Bg.
11	Genesee	Thread	7 N.	7 E.	19,20	Burton	100*	Very heavy	Kesten	Ca., Lmb., Np.
11	"	Swift's pond	6 N.	7 E.	34	Grand Blanc	5*	Heavy	Mr. Swift	Bg., Lmb., Ps., Bh., Np.
11	Oakland	Huntoon	3 N.	9 E.	8,9	Waterford	42.5	Very heavy	I.F.R.	Bg., Lmb., Mp., Cs., Bh., etc.
11	"	Long	2,3 N.	8 E.	1,2,35,36	Commerce	150*	Very heavy	Cline, I.F.R.	Bg., Ps., Yp., Lmb., C., etc.
11	"	Robinson	3 N.	8 E.	2	White Lake	20.3	Very heavy	I.F.R.	Bh., Gs.
11	"	Mud	1 N.	8 E.	3,10	Novi	25*	Fairly heavy	I.F.R.	Bg., Ps., Lmb., Np., Mp., Rb., Yp.
11	"	Richmond	3 N.	9 E.	16	Waterford	7*	Heavy	I.F.R.	Bh., Yp., Gs.
11	"	Lower Straits	2 N.	8 E.	11,12,13,14	Commerce	100*	?	Local resident	?
11	Washtenaw	Green	1 S.	3 E.	21,22,27,28	Lyndon	90.5	Very heavy	I.F.R.	Ps., Bg., Yp., C., Bh., Cs., Lmb., etc.
11	"	West	1 S.	4 E.	30	Dexter	158	Very heavy	I.F.R.	Bg., Yp., Ps., Lmb., Bh., Cs., Mp., etc.
11	"	Mud	1 S.	3 E.	31	Lyndon	92	Heavy	I.F.R.	Bg., Lmb., Ps., Yp., C., Cs., etc.
11	"	Pendergast	1 S.	3 E.	29	Lyndon	8.5	Very heavy	Clark	?
11	"	Winnewana	1 S.	3 E.	28	Lyndon	17.6	Very heavy	Clark	?
11	"	First Sister	2 S.	5 E.	25	Scio	3.5	Heavy ?	I.F.R.	?
11	"	Wile's Lake	1 S.	6 E.	17	Northfield	4*	Heavy	Brushaber	?
Totals		54 lakes					7,075			

*Area figures marked by an asterisk are based on measurements of lake outlines given on county maps, and are assumed to be only approximate values.

Table 4

Estimated Mortalities Due to Winterkill in Several Southern Michigan Lakes,

Counts Made March 16-23, 1945

(Data compiled by L. A. Krumholz)

County	Lake	Area	Total dead fish	Total dead game fish	Total legal game fish	Number per acre: Total fish	Number per acre: Game fish	Number per acre: Legal game fish	Percentage legal game fish in estimated game fish population
WASHTENAW									
	Green	78.5	65,509	59,462	17,263	835	758	220	29.0
	West	158	35,127	32,377	16,187	222	205	102	50.0
JACKSON									
	Goose	427	81,838	70,958	24,499	193	167	58	41.5
	Batteese	100	179,640	177,640	41,712	1,796	1,776	417	23.5
	Merkle	88.5	28,720	21,335	8,021	325	241	91	37.6
OAKLAND									
	Huntoon	42.5	26,737	24,096	9,048	629	567	213	37.6
	Robinson	20	22,760	22,610	20,349	1,138	1,131	1,017	90.0
MONTCALM									
	Duck ✓	306	50,000	45,000	33,750	163	147	110	75.0
Total or average for seven lakes (exclusive of Duck)		912.5	440,331	408,478	137,079	483	448	150	33.6

✓ No count made - estimate only

Table 5

Number of each species of fish taken by gill and fyke nets from 16 of the winterkill lakes, spring of 1945 (i.e., after the winter mortality).

County	Name of lake	Date of netting, 1945	Nets✓ used in over-one-night sets	Largemouth bass	Bluegill	Northern pike	Yellow perch	Pumpkinseed sunfish	Black crappie	Lake chubsucker	Brown bullhead	Yellow bullhead	Mud pickerel	Golden shiner	Other species
Newaygo	Pettits	May 8-9	375 ft. of gill nets	..	..	1	2	..	..	..	..	..	..	..	
Montcalm	Duck	May 8-9	690 ft. of gill net	..	..	3	3	..	..	..	..	..	..	24	
	Mud (in Crystal)	May 9-10	375 ft. of gill net	1	2	1	4	..	..	..	..	2	..	..	1 Rock bass
	Mud (in Evergreen)	May 9-10	690 ft. of gill net	1	1	7	1	..	1	..	..	2	..	6	3 White sucker 2 Warmouth bass
Kalamazoo	Dustin	May 17-18	565 ft. gill net	..	..	..	..	..	..	..	..	..	..	89	354 Black bullhead
	Twin	May 17-18	375 ft. of gill net	..	..	..	..	..	..	25	..	..	8	275	
	Bonnie Castle	May 17-18	375 ft. of gill net	..	..	..	..	..	..	..	..	..	..	..	21 Black bullhead
St. Joseph	Evans	May 18-19	815 ft. of gill net	..	..	..	2	..	..	..	..	..	..	343	7 Mud minnow
Barry	Loomis	May 20-21	500 ft. of gill net	..	..	..	29	..	..	..	..	..	..	85	
Jackson	Merkle	Apr. 12-13	2 fykes, 890 ft. of gill net	..	..	..	..	..	..	..	49	6	..	39	1 Bowfin
	Batteese	Apr. 11-12	2 fykes, 890 ft. of gill net	1	6	8	75	9	18	1	52	12	1	136	1 Warmouth bass 1 Bowfin
	Goose	Apr. 13-14	2 fykes, 890 ft. of gill net	4	1	..	58	8	..	193	60	27	5	45	1 Bluegill X sunfish 3 Bowfin
Oakland	Huntoon	Apr. 16-17	2 fykes, 890 ft. of gill net	..	..	..	166	..	..	34	..	38	..	8	
	Long	Apr. 17-18	2 fykes, 890 ft. of gill net	..	..	..	6	..	..	..	..	2	..	2	
Washtenaw	Green	Apr. 9-10	2 fykes, 1,840 ft. of gill net	..	..	..	93	12	1	281	..	123	37	171	
	West	Apr. 10-11	2 fykes, 890 ft. of gill net	..	..	20	6	..	..	5	1	5	..	1	
Genesee	Swift's	Apr. 24-25	125 ft. of gill net	No fish											

✓ The gill netting used was about half the experimental type of gill net and half straight meshed nets, but the straight meshed nets were combined in units to give a net with several mesh sizes. Thus each lake was fished either with experimental nets of 1 1/2 to 4 inch mesh, or with straight-mesh nets ranging from 1 1/4 to 3 inch mesh. The two fykes were the hoop type, 3 feet in diameter, with wings but no lead.

DISSOLVED OXYGEN IN LAKES IN THE WASHTENAW — JACKSON AREA. WINTER OF 1944-45
(DEPTH OF SAMPLE GIVEN BELOW EACH COLUMN)

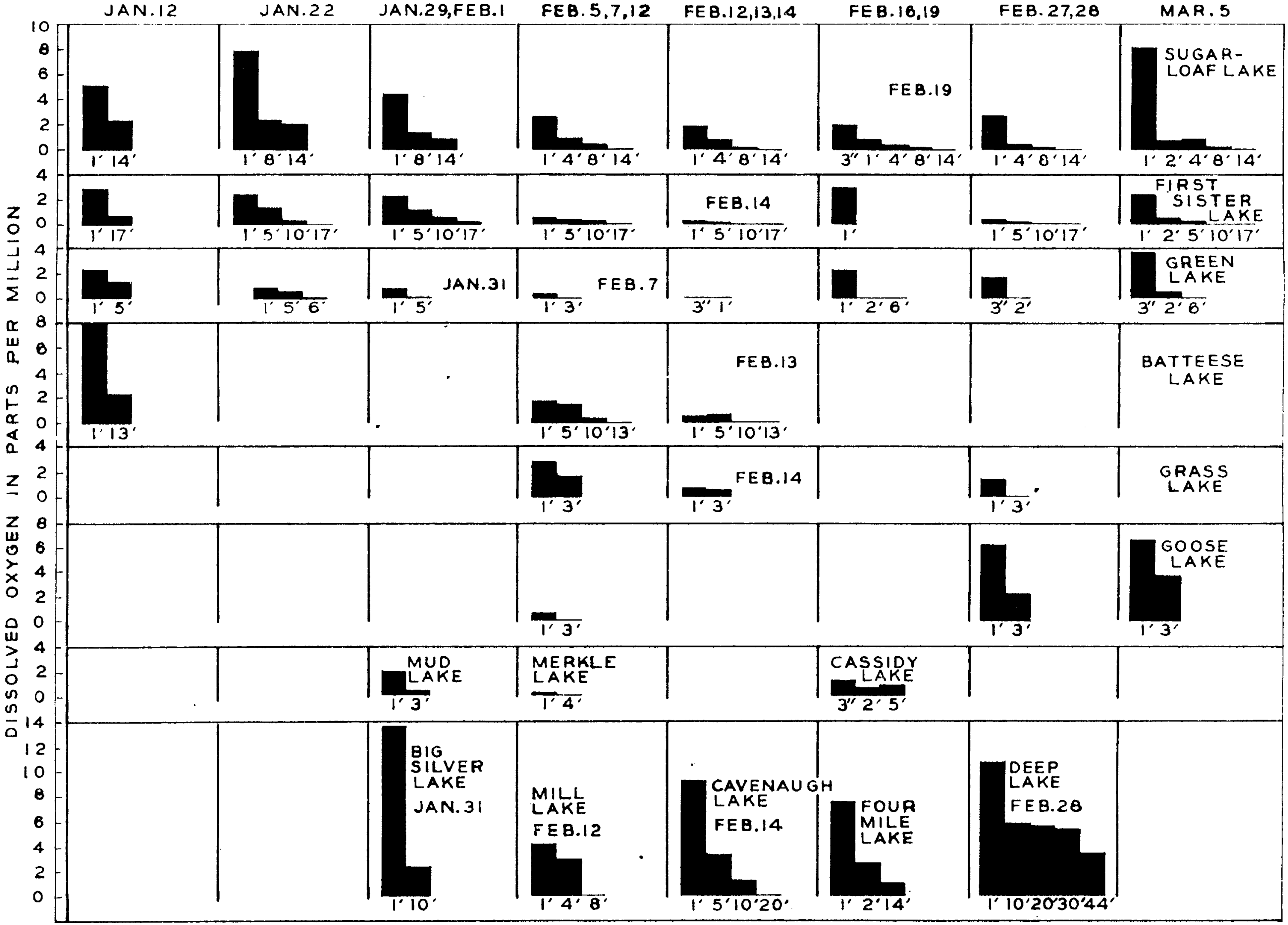

Figure 1

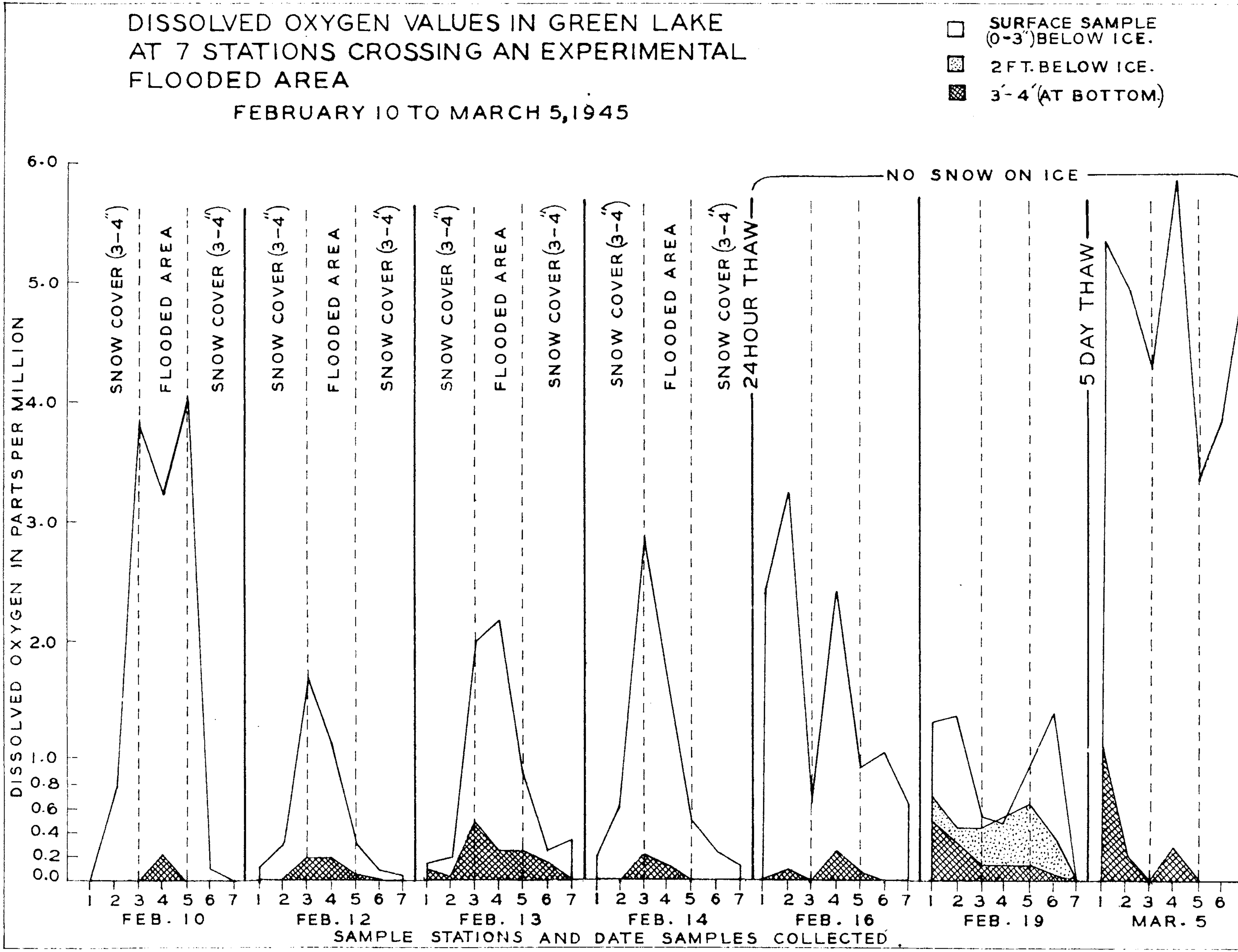
DISSOLVED OXYGEN VALUES IN GREEN LAKE
AT 7 STATIONS CROSSING AN EXPERIMENTAL
FLOODED AREA
FEBRUARY 10 TO MARCH 5, 1945
SURFACE SAMPLE (0-3")BELOW ICE.
2 FT. BELOW ICE.
3'-4' (AT BOTTOM.)
NO SNOW ON ICE
SNOW COVER (3-4")
FLOODED AREA
24 HOUR THAW
5 DAY THAW
DISSOLVED OXYGEN IN PARTS PER MILLION
6.0
5.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7
FEB. 10
FEB. 12
FEB. 13
FEB. 14
FEB. 16
FEB. 19
MAR. 5
SAMPLE STATIONS AND DATE SAMPLES COLLECTED

Figure 2