

THE EFFECT OF HIGH CONCENTRATIONS OF DISSOLVED OXYGEN ON SEVERAL SPECIES OF POND FISHES.

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INTRODUCTION.

The investigation of this problem was undertaken for two reasons: first, because investigations of the oxygen content of pond waters have shown that at times when photosynthesis is proceeding at a rapid rate, the water is supersaturated with dissolved oxygen and second, because of the coming into use of compressed oxygen in aerating fish during transportation. In a paper by Wiebe (1931) it has been shown that in one of the fish ponds the water was saturated 189.50%. Unpublished data obtained at this laboratory by Mr. A. M. MacGavock during the summer of 1931 show that in one of the bass ponds the percentage of saturation of the surface water ranged from 164% at 8:00 A. M. to 304% at 5:00 P. M. The next morning at 7:00 o'clock it was down to 153%. The mass production of O₂ in this case was due to an enormous growth of the blue-green alga, *Anabaena*. In 1928 the water in one of the ponds contained 4.68 p. p. m. of dissolved oxygen at 8:00 A. M. and 15.90 p. p. m. at 3:00 P. M. of the same day, Wiebe (1930).

The effect of high concentration of oxygen on fishes has been studied by Shelford and Allee (1913), by Wells (1913), by Haempel (1928), and by Plehn (Praktikum der Fischkrankheiten). Hubbs (1930) has investigated the effect of nascent oxygen on fish.

METHOD OF PROCEDURE.

The containers used in these experiments were large glass carboys, an iron preserving kettle, and specially constructed fish cans. These containers were so equipped that they could be attached to a tank of compressed oxygen and with an outlet so that water could be displaced by oxygen and samples withdrawn without opening the container. In the glass carboy it was possible to observe the reaction of the fish during the

experiment. This was not possible in the other containers mentioned. The ability of the fish to survive the experiments for shorter or longer periods was used as a criterion.

The experiments are primarily of two types and the results are presented under two sections, A and B. In the first group of experiments the fish were subjected to high concentrations of oxygen under atmospheric pressure with an atmosphere of pure oxygen over the water. In the second group the fish were subjected to pressure of varying degrees. In most of these pressure experiments a layer of pure oxygen was maintained over the surface of the water. The pressure readings were taken in whole and in half pound intervals on a pressure gauge. Then the gauges were calibrated for each scale interval against a mercury monometer. More specific details are given below.

Species of fish used were: largemouth black bass, *Micropterus salmoides*, (Lacepede); smallmouth black bass, *M. dolomieu* (Lacapede); the black crappie, *Pomoxis Sparoides* (Lacepede); the white crappie, *P. annularium* (Rafinesque), the bluegill, *Lepomus incisor* (C. and V.); the golden shiner, *Notemigonus crysoleucas* (Mitchill); the common goldfish, *Carassius auratus* (L.); the orange spotted sunfish, *Lepomus humilus* (Girard); the brook trout, *Salvelinus fontinalis* (Mitchill), and the rainbow trout, *Salmo shasta* (Jordan).

Section A.

Experiments to show, (1) that various species of pond fish can live in water with a stratum of pure oxygen over the water, and (2) that they can stand a sudden transition from water with a low oxygen content to water of a relatively high oxygen content and the reverse.

The experiments were carried out in large glass carboys. The procedure was as follows: The container was completely filled with water before the fish were introduced. After the fish had been put in the container the latter was stoppered tightly and connected to a tank of compressed oxygen. The gas was released close to the bottom of the container. The carboy was also equipped with an exit tube so that some of the water could be displaced by oxygen. In this manner a layer of pure oxygen was established. Preliminary experiments have shown that if the oxygen is introduced near the bottom of the container, it takes only a relatively short time until the

concentration of oxygen becomes fairly uniform throughout the entire mass of water. Samples for oxygen determination were taken close to the bottom. In some experiments, No. 2, for instance, samples were taken at different depths after the fish had been introduced, but no significant difference in the amount of oxygen was discovered. In some instances the oxygen in the experimental container was increased by bubbling oxygen through the water before the fish were introduced. This was done in order that it might be determined if fish can stand a sudden transfer from low to high oxygen tension.

EXPERIMENT 1.

Smallmouth Black Bass Fry.

In this experiment 160 smallmouth bass fry ranging in size from 0.5" to 0.75" were used. They were taken from pond water having an O₂ content of 10.62 p. p. m., a pH of 9.3, and a temperature of 23.5° C.

TABLE I.

Shows O₂ in Parts per Million, Temperature in Degrees Centigrade, and pH Value for Experiment Number 1.

Date	Hours	O ₂	pH	Temperature	Remarks
5-31-31	2:30 P. M.	20.75	7.3	23.5	Initial condition in carboy when fry were introduced.
5-31-31	5:00 P. M.	28.38	.....	.....	.....
5-31-31	9:45 P. M.	30.71	.....	.....	.....
6- 4-31	5:30 A. M.	30.71	.....	.....	When the experiment was terminated the CO ₂ amounted to 25 p. p. m.
6- 4-31	3:00 P. M.	30.05	7.25	19.5	.....

and placed in a carboy whose water had an O₂ content of 20.75 p. p. m., a pH of 7.3, and a temperature of 20.0° C. After the fish had been put in the container the latter was stoppered tightly and some of the water displaced by oxygen, thus creating a layer of pure oxygen over the surface of the water. The experiment was begun at 2:30 P. M., May 31, and was terminated at 3:00 P. M., June 1st. Sufficient fresh water was added at this time to again fill the carboy completely reducing the O₂ to 21.58 p. p. m. Additional data for O₂, etc., are shown in Table I.

No fish were lost during this 24-hour experiment. When the carboy was opened and some water fleas and small shiners put in, the bass fed on them very readily. The fish were kept under

observation in this carboy for a week, the water being aerated with compressed air. No fry died during this period.

At no time did these fish show any signs of uneasiness while they were under an atmosphere of pure oxygen. This together with the fact that they survived so well and took food so readily would seem to show that this treatment had no deleterious effect on these little fish.

EXPERIMENT 2.

Largemouth Black Bass Fry.

The procedure in this experiment was the same as in number one. The fish used were 150 largemouth fry 0.5" to 0.75" in length. They were transferred from water having a pH of 7.9, O₂ content of 7.21 p. p. m., and a temperature of 24.0° C., to water having a pH of 7.5, an O₂ content of 27.25 p. p. m., and a temperature of 20.0° C. This experiment was begun at 10:00 A. M., June 4.

At 1:30 P. M. two oxygen samples were taken from this carboy: one at 2" below the surface and another at 8". The former sample had an O₂ content of 31.99 p. p. m., and the latter had 31.44 p. p. m. At 5:20 P. M. two samples were taken at 1.5" and 7.5" respectively. The O₂ content of both samples was 32.75 p. p. m.

At 5:00 P. M. the O₂ 1" below the surface was 30.65 p. p. m., and at 7" below the surface it was 29.87 p. p. m. At 9:00 A. M. June 6, the O₂ 7" below the surface was 32.75 p. p. m., pH 7.1, free CO₂ 15.1 p. p. m., and temperature 19.0° C. The experiment was discontinued at this time. The carboy was refilled with water and the latter aerated with compressed air. The fish were kept under observation until June 11. Up to that time three fry had died.

It would appear from the above that the sudden transfer from an O₂ content of 7.1 p. p. m. to 27.25 p. p. m. did not harm these bass fry and that they could live in water under an atmosphere of pure oxygen.

EXPERIMENT 3.

Smallmouth Black Bass Fingerlings.

Procedure same as in number two. Fish used were 75 smallmouth bass having an average length of 1.75". They were transferred from water with an O₂ content of 6.42 p. p. m. to water whose O₂ content was 22.7 p. p. m. The transfer was made at 11:00 A. M. July 10. The temperature in the trough was 21.5° C. and the pH 7.6; the temperature in the carboy was 23.0° C. and the pH 7.2. For additional data on O₂, etc., see Table II.

The experiment was discontinued at 9:00 A. M. July 12, and the fish transferred to water having an O₂ content of 6.0 p. p. m. The fish seemed none the worse for this experiment.

They learned to take artificial food in a few days and acted normally in all respects. No fish were lost during the experiment. The same was true of the control fish. These fish were kept under observation until July 27, i. e., until 17 days after the experiment was begun. During this period only one experimental bass was lost—this one was dead on July 13. The control fish all survived up to this time.

TABLE II.

Shows O₂ and Free CO₂ in Parts per Million, Temperature in Degrees Centigrade, and pH Value for Experiment Number 3.

Date	Hour	O ₂	pH	Temperature	Free CO ₂	Remarks
7-10-31	11:00 A. M.	22.7	7.2	23.0	Initial conditions
7-10-31	1:00 P. M.	24.69	.....	.....	.....
7-11-31	8:00 A. M.	20.28	7.0	24.0	35.2	
7-11-31	5:00 P. M.	21.2	7.0	23.5	39.6	
7-12-31	8:00 A. M.	18.2	6.9	23.0	47.5	

The above results would certainly seem to indicate that this size of smallmouth bass could live in water with a superstratum of pure oxygen for a period of 46 hours. Moreover, that they could stand a sudden transition from water having an O₂ content of 6.42 p. p. m. to water having 22.7 p. p. m., and from 18.2 p. p. m. to 6 p. p. m.

EXPERIMENT 4.

Largemouth Black Bass Fingerlings.

This is an exact repetition of number three, only that 50 largemouth bass having an average length of 2.64" were used instead of smallmouth bass. This experiment was carried on simultaneously with number three and the values for O₂, pH, free CO₂, and temperature are essentially the same as in number three, hence they are omitted. Only the results as far as the fish are concerned are recorded here.

Three bass were lost during this experiment while none of the controls died during the 44-hour period. The remaining fish were kept under observation until July 27. Up to that time 4 more of the experimental bass had died and two of the controls. Although the losses here are greater than in number three, it is still very doubtful that the death of these fish was caused by the high oxygen. The fact that two of the controls also died points the other way. Also the experimental fish were handled more than the controls. This may have had something to do with the greater mortality.

EXPERIMENT 5.

Trout Fingerlings.

The procedure in this experiment is the same as in the preceding experiments. The fish used were 10 rainbow and 10 brook trout that had an average length of about 2.5" to 3". The fish were taken from water having an O₂ content of 5.68 p. p. m., and 6.68 p. p. m. They were transferred to water having an O₂ content of 17.1 p. p. m., free CO₂ 1.5 p. p. m. The temperature varied from 22.0 to 23° C. during this experiment. Additional observations made during the test period which lasted from 8:00 A. M. July 13 to 8:30 A. M. July 15, are shown in Table III. At this time enough fresh water was added to reduce the O₂ to 10.9 p. p. m. The fish were all in good condition. They were kept under observation until July 23. Only one trout had died up to that time. Hence it seems that to live for 48.5 hours in water under a super-stratum of oxygen produced no ill effect in these fish. (It may be noted here that the temperatures that prevailed during this experiment were unfavorable for these small trout.)

TABLE III.

Shows O₂ in Parts per Million, Temperature in Degrees Centigrade, for Experiment Number 5.

Date	Hour	O ₂	Temperature	Free CO ₂
7-13-31	4:30 P. M.	23.7	22.0	.....
7-14-31	8:30 P. M.	26.2	22.5	.....
7-15-31	8:30 P. M.	37.6	22.5	.....

From the results of this experiment it would appear that these small trout could stand a sudden and extensive change in the concentration of dissolved oxygen.

EXPERIMENT 6.

Black Crappie and Bluegill Fingerlings.

The experiment was begun at 11:00 A. M. May 23. At that time 12 black crappie 2.5" to 4" and 23 bluegill 1.5" to 2.5" were transferred to an experimental carboy, and 13 black crappie and 10 bluegill of the same size to a control carboy. In the control the water was aerated with compressed air. In the experimental carboy the O₂ content of the water had been raised by bubbling O₂ through the water before the fish were introduced. After the fish were in the carboy some of the water was displaced with O₂. At the time of the transfer the O₂ in the retaining trough was 3.32 p. p. m., in the experimental carboy the O₂ amounted to 22.41 p. p. m., and in the control 5.48 p. p. m. During the test period the O₂ in the control varied between 4.15 p. p. m. and 7.8 p. p. m. The temperature in both carboys ranged from 17.0° C. to 17.5° C.

Additional oxygen values for the experimental carboy are shown in Table IV. At the end of the experiment the free CO₂ amounted to 7.5 p. p. m. in the experimental carboy. The experiment was terminated at 1:00 P. M. May 25.

At the end of the experiment one of the experimental bluegill was sick and two of the control crappie were dead. Up to May 30, 21.7% of the experimental and 40.0% of the control bluegill had died. At the same time 8.33% of the experimental crappie and 46.1% of the control crappie had died. After that no losses occurred for several days, and the fish were liberated. From these results it would appear that

TABLE IV.

Shows Values for O₂ in Parts per Million for Experiment Number 6.

Date	Hour	O ₂	Date	Hour	O ₂
5-23-31	1:00 P. M.	25.89	5-24-31	10:00 A. M.	24.88
5-23-31	6:00 P. M.	27.89	5-25-31	8:00 A. M.	21.08
5-23-31	9:45 P. M.	26.72	5-25-31	1:00 P. M.	20.92

these fish had been benefited by the high concentration of oxygen. (It may be well to mention here that these were rescued fish.) The fish that survived the experiment took food readily.

EXPERIMENT 7.

Two-year Old Bluegill.

The procedure in this experiment was the same as in number 5, and it was begun at 4:00 P. M. May 26. In this experiment 10 two-year old bluegill were used. The same number was used for a control. The fish were taken from water having an O₂ content of 2.65 p. p. m. The water in the experimental carboy had an O₂ content of 25.73 p. p. m. at the time the fish were introduced. During the test period the O₂ ranged from 24.03 p. p. m. to 31.87 p. p. m., while the range in the control was from 4.48 p. p. m. to 8.13 p. p. m. The temperature ranged from 18 to 21.5° C. The experiment lasted for 45 hours. At the end of the experiment the fish were transferred to separate compartments of an aquarium. The O₂ in this aquarium amounted to 6.31 p. p. m. Each carboy had one dead fish and one sick fish at the end of the experiment. The dead as well as the sick fish showed definite skin lesions. (The two-year old bluegill had been given a copper sulphate bath a few days before the experiment was begun. They were badly fungused before the treatment.) Two of the experimental and one of

the control fish were dead on May 29; all had definite skin lesions. The fish were kept under observation for two more weeks, but no more losses occurred. The fish were now entirely free from fungus and took food very readily.

Total loss of fish was three experimentals and two controls. Hence it may be concluded that the high oxygen and the atmosphere of pure O₂ over the water had no ill effect on these fish.

EXPERIMENT 8.

Largemouth Bass Fingerlings.

Procedure was as in experiment number 7. Fish used were: 6 largemouth bass from 4.25" to 5.25" in length. The O₂ content of the water in the experimental carboy had been raised to 40.33 p. p. m. before the fish were introduced. The fish were transferred to this carboy from water having an O₂ content of 5.67 p. p. m. Observations on O₂, and temperature are shown in Table V.

TABLE V.

Shows O₂ in Parts per Million, and Temperature in Degrees Centigrade for Experiment Number 8. The Per Cent Saturation is Referable to an Atmosphere of Ordinary Air.

Date	Hour	O ₂	Temperature	% Saturation
1-27-31	10:10 A. M.	40.33	16.5	410
1-27-31	1:00 P. M.	37.49	16.5	381
1-27-31	4:00 P. M.	35.97	16.5	366
1-28-31	9:00 A. M.	29.43	17.0	302

These fish showed no signs of restlessness when put in the water of high oxygen content. They all survived the experiment and were kept under observation for several days before they were returned to the retaining trough. The sudden transfer from low to high oxygen and the 23-hour stay in water under an atmosphere of pure oxygen had no deleterious effect.

Additional experiments involving more than a hundred largemouth bass, several smallmouth bass, more than 200 golden shiners, several bluegill, at least 50 goldfish, and several crappie all gave essentially the same results.

Section B.

This section deals with the results of experiments designed for the purpose of determining the ability of fish to live under small pressures.

EXPERIMENT 9.

Bass, Sunfish, Goldfish and Shiners.

In this experiment an iron preserving kettle was used as a container for the fish. The procedure was essentially the same as in Section A except that no water was displaced and that the oxygen was introduced over the surface of the water instead of being bubbled through the water from the bottom. The result of this modified procedure was a much lower O₂ content of the water, namely, 13.64 p. p. m. at the conclusion of the experiment. The temperature ranged between 17.5 and 18.0° C.

The fish used in this experiment were: 4 largemouth black bass (4.25" to 5.5"), 2 goldfish (3" to 3.5"), 1 green sunfish (2.25"), and 8 golden shiners (4" to 5.5"; this does not include two smaller shiners eaten by the bass in the course of the experiment).

In this experiment a pressure of 7 to 9 lbs. was maintained from 11:30 A. M. to 1:40 P. M. Then from 1:40 P. M. to 11:30 P. M. a pressure from 12 to 13.2 lbs. was maintained. The fish were taken out at 12 o'clock midnight and transferred to water that had an O₂ content of 13.62 p. p. m. No fish except the two shiners consumed by the bass were lost in the experiment. However, one of the larger shiners had several blood stains on its sides. The rest of the fish showed no visible signs of injury. The apparently injured shiner acted perfectly normal, and when these fish were returned to the holding troughs after having been kept under observation for two weeks, was alive and healthy. Since no fish were lost and since the fish acted normally and took food readily, it is concluded that an increase in pressure of from 0.46 to 0.88 atmosphere above normal exerted no deleterious effect on these fish.

EXPERIMENT 10.

Bass, Goldfish and Shiners.

This experiment was carried out in two stages. The pressure cooker was again used as a container. In the first part of the experiment the O₂ was bubbled through the water while in the second part it was introduced over the surface of the water. The fish used in part 1 were: 3 largemouth bass (4" to 5"), 1 smallmouth bass (5"), 3 goldfish (3" to 3.25"), and 2 shiners (3" to 3.25"—this does not include several small shiners eaten by the bass in the course of the experiment). The pressure

records for part 1 are shown in Table VI. The initial O_2 was 7.92 p. p. m. at a temperature of $17.5^\circ C$. At the conclusion of part 1 the O_2 was 38.5 p. p. m. at a temperature of $16.5^\circ C$.

TABLE VI.

Shows Pressure Reading for Part One of Experiment 10 in Pounds.*

Hour	Pressure	Hour	Pressure	Hour	Pressure
10:35 A. M.	0 lbs.	11:20 A. M.	18.6 lbs.	12:40 P. M.	17.6 lbs.
10:55 A. M.	12.1 lbs.	11:25 A. M.	17.1 lbs.	1:05 P. M.	17.6 lbs.
11:00 A. M.	12.1 lbs.	11:30 A. M.	17.6 lbs.	1:10 P. M.	17.6 lbs.
11:04 A. M.	15.4 lbs.	11:35 A. M.	18.6 lbs.	1:15 P. M.	17.6 lbs.
11:05 A. M.	17.6 lbs.	11:40 A. M.	19.6 lbs.	1:20 P. M.	7.85 lbs.
11:10 A. M.	17.6 lbs.	11:45 A. M.	17.6 lbs.	1:25 P. M.	4.30 lbs.
11:15 A. M.	17.6 lbs.	12:05 P. M.	17.6 lbs.	1:30 P. M.	0 lbs.

Part 2 of this experiment was begun at 2:15 P. M. after a 3-inch bluegill had been added. The rest of the fish were the same as in Part 1. The pressure was raised again, but instead of bubbling the O_2 through the water, it was introduced over the surface of the water. The result was that the dissolved oxygen increased only very little during Part 2 of this experiment, namely, from 38.5 p. p. m. to 39.82 p. p. m. The pressure records for Part 2 are given in Table VII.

TABLE VII.

Pressure in Pounds for Part Two of Experiment 10.

Hour	Pressure	Hour	Pressure	Hour	Pressure
2:15 P. M.	0 lbs.	2:45 P. M.	18.6 lbs.	3:45 P. M.	17.6 lbs.
2:17 P. M.	7.17 lbs.	2:55 P. M.	18.6 lbs.	4:00 P. M.	17.6 lbs.
2:30 P. M.	7.85 lbs.	3:05 P. M.	18.6 lbs.	4:20 P. M.	17.6 lbs.
2:40 P. M.	12.10 lbs.	3:20 P. M.	18.6 lbs.	4:40 P. M.	17.6 lbs.

During the interval from 4:40 P. M. to 4:50 P. M. the pressure was reduced from 17.6 lbs. to 0 lbs. The cover was then removed and the fish examined. The fish were on the bottom of the container apparently perfectly at ease.

The fish were left in this container until 8:00 A. M. the next morning, when they were transferred to a holding trough. The fish were all alive and active. Several small shiners had

**Note.*—During the intervals between readings the pressure was maintained between the values shown for consecutive readings, i. e., during the interval between 11:20 A. M. and 11:25 A. M. the pressure was never below 17.1 lbs. or above 18.6 lbs.

been eaten by the bass during the experiment. The small-mouth bass had a shiner in its mouth at the time of the transfer. These fish showed no sign of injury whatsoever.

This experiment suggests that these fish could adapt themselves rapidly to an increase in pressure slightly in excess of 2 atmospheres.

In the last two experiments due to the peculiar construction of the iron kettle it was not possible to create a layer of pure oxygen over the water.

EXPERIMENT 11.

Bass, Goldfish, Sunfish and Golden Shiners.

In this experiment fish were subjected to a pressure of 9.85 lbs. for 10.5 hours with a layer of pure oxygen over the surface of the water. A glass carboy was used as a container for the 5 largemouth (3.5" to 5.5"), 3 goldfish (3" to 3.5"), 2 bluegill (2.75" to 3"), and 15 golden shiners (2.5" to 5"). For a few minutes during and after the pressure was raised the fish were slightly restless, but they soon became quiet and remained so during the entire test period. (This does not mean motionless, for they moved around freely at all times.)

This experiment was begun at 11:00 A. M. February 13. The following values for O_2 obtained during this experiment at the time indicated: 12:15 P. M., 19.53 p. p. m.; 2:40 P. M., 26.91 p. p. m.; 7:45 P. M., 39.06 p. p. m.; at 9:30 P. M., 42.53 p. p. m. At this time the oxygen tank was disconnected and the pressure allowed to go down to zero in a few minutes. The fish were kept in the carboy until 8:00 A. M. of the next day, at which time they were transferred to an aquarium. The oxygen in the carboy still amounted to 26.26 p. p. m. at the time of transfer. The fish were all in fine condition and apparently had suffered no adverse effect from the conditions of the experiment. On February 28, i. e., fourteen days after the experiment was terminated, all the fish with the exception of the two smallmouth were still alive and healthy. The two smallmouth were dead on February 17, three days after the termination of the experiment. At the time of their death the O_2 in the aquarium was down to 1.08 p. p. m. This was apparently too low for the smallmouth. The other species could survive the low O_2 because they are less timid and come and snap for air at the surface more freely.

NOTE: Some of the bass used in this experiment were still alive in June and July, when they were used in experiments to determine the amount of arsenic in bass.

EXPERIMENT 12.

Bass and Trout.

The object of this experiment was to determine if fish considerably smaller than the ones used in experiments 9 to 11 could live under pressure with a super-stratum of pure oxygen. The container used was built of galvanized iron and was air tight. It was also equipped with an inlet for the gas and an outlet for water. The procedure was as follows: The can was completely filled with water before the fish were introduced. After the fish had been put in and the cover tightened down, the can was connected to an oxygen tank and some of the water displaced so that a layer of pure oxygen was formed over the surface of the water. After sufficient water had been displaced the pressure was raised 13.23 lbs. This pressure was attained at 2:30 P. M. July 14, and maintained until 8:30 P. M. of the same day. During the intervals between 8:30 P. M. and 7:30 A. M. the next morning the pressure went down to 11.15 lbs. At 7:30 A. M. the pressure was again raised to 13.23 lbs. by the introduction of additional O₂ and maintained there until 2:45 P. M. July 15. At this time the pressure was reduced to zero rapidly and the fish removed from the water in the can that had an O₂ content of 41.0 p. p. m. to water having an O₂ content of 7.3 p. p. m. The temperature ranged from 21.5° C. to 22.5° C. during the course of this experiment.

TABLE VIII.

Record of Fish.

Species	Size of Fish	Dead at End of Experiment	Alive at End of Experiment
Largemouth bass	1.25"-2"	3	33
Smallmouth bass	1" -1.4"	0	21
Trout.....	2.5"	2+1 sick	7
Total dead....	.....	5+1 sick	Alive 61

These results show that these small fish could stand a pressure of from 11.14 to 13.23 lbs. in excess of one atmosphere for a period of 24 hours. The large-mouth bass had been seined in one of our ponds just before the experiment was begun. While this experiment was in progress four of the largemouth in the retaining trough died, as did also several trout. It must be stated here that the temperatures prevailing during the experiment were beyond the range that is normal for these species of trout (rainbow and brook). From the time the experiment was terminated (July 15th) until August 11, only one individual of each species of bass had died—one large-

mouth was dead on July 30 and one smallmouth on August 6. The trout died as follows: July 16, 1; July 19, 1; July 26, 1; July 28, 3. The remaining trout has disappeared, probably eaten by the bass. All the trout in the retaining pond had likewise died. Hence the death of the trout may not be attributed to the fact that these fish were kept under pressure for 24 hours. Experiment 5, Section A, proves that it was not the high O₂ that proved detrimental.

EXPERIMENT 13.

Bass, Goldfish and Sunfish.

Procedure here was the same as in number 12. Fish used were 9 largemouth bass (4" to 5"), 9 goldfish (2.5" to 3.5") and 12 bluegill (2.0" to 3.0"). These were all tame fish and accustomed to taking artificial food. This experiment was begun at 4:30 P. M. July 14.

A pressure of 13.61 lbs. was attained at 4:45 P. M. At 8:30 P. M. the pressure was down 12.99 lbs. At 7:30 the next morning the pressure was down to 9.85 lbs. The pressure was raised to 12.99 lbs. at that time and retained there until 4:45 P. M. At 2:45 P. M. the O₂ amounted to 41.2 p. p. m. The temperature varied around 22° to 23° C. during this experiment. The fish were taken out of the experimental container at 4:45 P. M. and put in water having an O₂ content of 7.3 p. p. m. When the fish were taken out 3 bluegill were dead. The rest of the fish were apparently in good condition; they immediately began to take minnows and artificial food. On July 16 another bluegill was dead. No additional losses had occurred up to September 8. Apparently then most of these fish were not affected adversely by a pressure ranging from 9.85 to 13.61 lbs. in excess of one atmosphere for 24 hours.

EXPERIMENT 14.

Bluegill.

Procedure as in 12 and 13. Fish used were: 30 bluegill from 2" to 3" in length. (These fish had recently been rescued from a slough in Illinois.) The fish were placed in the container at 9:45 A. M. July 16 and the pressure raised promptly to 13.23 lbs. This pressure was maintained for 24 hours by keeping the oxygen tank connected with the fish container. Just before the experiment was ended at 9:45 A. M. July 17, the O₂ in the container was 39.2 p. p. m. The temperature ranged from 21° to 22° C. during the course of the experiment. Thirty minutes were used this time to reduce the pressure to zero. When the can was opened, two fish still alive were floating on the surface of the water. The other fish were all at rest on the bottom. All of these fish were then transferred to water having an O₂ content of 10.6 p. p. m. The two sick fish recovered to some extent after the transfer so that at 4:00 P. M. all the fish were swimming around naturally. On July 18, one bluegill was dead, and on the 19th 3 more were dead. Two of these showed skin lesions. The rest of the fish were feeding at that time.

Several bluegill in the retaining trough which served as controls had also died during this time. From July 19 to September 8 no additional fish had died. In view of the fact that two of these dead fish showed definite skin lesions and also since some of the control fish died, the assumption seems warranted that the death of these fish was not caused by the pressure and that healthy bluegill of this size could exist under a pressure of 12.23 lbs. under a super-stratum of pure oxygen for 24 hours. The transfer from water having an O₂ content of 39.2 p. p. m. to water having 10.6 p. p. m. was also withstood by these fish.

EXPERIMENT 15.

Crappie and Sunfish.

The procedure in this experiment is the same as in the preceding one. Fish used were: 7 crappie ranging in size from 4" to 5½", 3 bluegill (3.25" to 4.75"), and 1 orange spotted sunfish (2.75"). A pressure of 12.99 lbs. was attained at 1:00 P. M. July 29. At 4:00 P. M. the pressure was still 12.99 lbs., but at 9:00 P. M. it was up to 13.45 lbs. At 7:30 the next morning the pressure was down to 12.4 lbs. This pressure was maintained until 1:00 P. M., when it was reduced to zero fairly rapidly. Before the pressure was released the O₂ amounted to 38.2 p. p. m. When the can was opened, 3 crappie were on their sides but still alive. The fish were taken out at 1:20 P. M. and transferred to water having an O₂ content of 7.1 p. p. m. Two of the sick crappie recovered in a few minutes, but the third one did not recover fully and on August 1 it was dead. The injury to the crappie was probably due to too rapid depression. The crappie that died had an injured air bladder. Four of the crappie, the bluegills, and the orange spotted sunfish showed no ill effects at any time. Up until October 1 only the one crappie had been lost, i. e., one fish out of eleven. Hence it would appear that a pressure of from 12.99 to 13.45 lbs. exerted for 24 hours is not harmful to these larger bluegill and crappie.

DISCUSSION OF RESULTS.

The results given above seem to show that the species of fish used in these experiments can for short periods of time endure relatively high concentrations of dissolved oxygen without producing any immediate ill effects. From the data of some of the experiments it would appear that apparently no ill effects had been produced considering the length of time that the fish were kept under observation. (See especially Experiments 3, 4, 13, 14 and 15.) It is also quite apparent that pressures as high as 13 lbs. can be endured for 24 hours. And pressures as high as 15 to 19 lbs. for a couple of hours. It has not yet been determined whether these fish could endure these higher pressures for longer periods of time.

The phenomenon of air bubbles that was observed by Shelford and Alee (1913) was absent entirely in these experi-

ments. These authors, under the heading "Effect of a great excess of nitrogen and oxygen," record the occurrence of gas bubbles developed in the fins of several species of fish. The water they used contained excess gas to the extent of 1 c. c. per litre of both nitrogen and oxygen. In my experiment the water was supersaturated with oxygen to a very much higher degree. The per cent of saturation has been recorded only in one of our experiments (Number 8), there it reached 410%, i. e., 310 per cent supersaturation. It may, therefore, be assumed that the gas bubbles referred to by these authors were due to the excess nitrogen and not the slight excess of oxygen.

Plehn attributes the occurrence of exophthalmus in trout to the supersaturation of the blood with oxygen. She says, moreover, "dass auch Cypriniden Barsche (Barsche-yellow perch as well as our two species of black bass) wahrscheinlich alle Fische—durch zuviel Sauerstoff zugrunde gehen. Bei ihnen ist Gasblasenbildung aeusserlich nicht sichtbar—Als auffallendstes Merkmal wird nicht selten eine Truebung der Hornhaut und bei laengerer Dauer auch eine linsen truebung beobachtet." No cases of exophthalmus, opaque lense, or darkening of the cornea were observed in the course of these experiments. She also speaks of the phenomena of irritability and convulsions. These effects were noticed in some of the experiments where larger numbers of the large bass fingerlings were used. In one experiment the details of which have not been included in the text, the bass began to stampede when disturbed. (This sometimes occurs under normal environmental conditions where the fish are confined.) This was on the third day after they had been in a container in which the oxygen was raised suddenly from 5.72 p. p. m. to 20.90 p. p. m., and then permitted to go down gradually. On the third day the O₂ amounted only to 10.41 p. p. m., but the CO₂ amounted to 150 p. p. m., and it was probably the latter that caused the nervousness in the fish. The fish all recovered when transferred to water of a lower O₂ and CO₂ content. In another experiment the fish began to show signs of discomfort on the fourth day of the experiment when the O₂ was down to 6.73 p. p. m. (Temperature, 17.0° C.) The CO₂ was in excess of 200 p. p. m. and was undoubtedly the factor responsible for the great irritability. The assumption that the irritability was not produced by the excess oxygen present at the beginning of the experiment is borne out by the fact that in several

experiments where even higher concentrations of O_2 were used no such irritability was developed.

Haempel (1928) exposed trout (rainbow and brook), carp, (*Cyprinus carpio* L.), Schill (*Lucioperca sandra* Cuv.) and Schleie (*Tinca vulgaris* Cuv.) to high concentrations of oxygen. The highest concentration of O_2 used by him on the trout (adults) was 45.18 p. p. m., the highest used on the carp (adults) 42.61 p. p. m. He noticed one case of opaque lens, but no signs of exophthalmus and of gas bubbles. He gives the results roughly as follows: A marked restlessness, which in the case of the Salmonidae ended in a stampede, marked by an increase in respiration (dyspnae). The young fishes (specially Salmonidae) are seriously injured. They soon turn on their back and pass into a condition of paralysis which he has designated as an " O_2 -Narkose." If the exposure to high O_2 is continued the fish die. According to Haempel, the young Salmonidae are more sensitive to the excess of O_2 than the adults. Loosanoff (unpublished data) found that the adult salmon were more sensitive to an excess of oxygen than the fingerlings were. Haempel also calls attention to an excessive production of slime. This was not observed in the experiment reported in this paper. Difference in the rates of respiration were observed.

The change in the rate of respiration for two bass and two bluegill were determined. The results showed that there is a pronounced tendency towards a reduction in the rate of respiration as the concentration of oxygen is increased.

SUMMARY.

(1) Several species of fish have been subjected to higher concentrations of dissolved oxygen when an atmosphere of pure oxygen was maintained over the surface of the water and also with a super-stratum of pure oxygen under pressure.

(2) Several species of fish have been subjected to sudden transfers from low O_2 to high O_2 and the reverse.

(3) The results show (a) that some species of fish tolerate large and sudden changes in the concentration of O_2 in either direction, namely, from 5.67 p. p. m. to 40.33 p. p. m. (Experiment 8), and from 41.2 p. p. m. to 7.3 p. p. m. (Experiment 13); (b) that these fish can live in water containing a large excess of dissolved oxygen with a super-stratum of pure oxygen over the surface (Experiment 9); (c) that several species of fish can stand

a pressure of 10 to 13 lbs. for a period of 24 hours (Experiments 12-15) and pressures from 15 to 19 lbs. for shorter periods (Experiment 10). Longer periods not investigated.

(4) The increase in dissolved oxygen is followed by a slowing down of the respiratory movements.

(5) No instances of exophthalmus, opaqueness of the lens, and of the formation of gas bubbles were observed.

(6) No fish were observed to lose their equilibrium except in a few instances in the pressure experiment where depression occurred too rapidly.

(7) That the exposure to high concentration of dissolved oxygen with a super-stratum of pure oxygen at atmospheric pressures and under small pressure is not harmful is inferred from the small number of fish lost and from the length of time for which a majority of the fish survived the experiment.

(8) The data presented here suggest that they may be applicable to the problem of handling fish during transportation.

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Glaciation.

For those interested in glaciation, especially in the New England region, this little book shows the possibilities of what can be compiled and observed by careful, close attention to a small area. The book is worth reading because of the completeness of the information it contains, although I can find no conclusions drawn from all this information. The general get up of the book is good with the exception of the two maps, both of which are crowded on their respective pages, allowing a margin of a scant one-eighth inch. The same may be said of the figures on page 19. I also note that the word schist is misspelled in several places.

WILLARD BERRY.

Alpine Zone of Mt. Washington Range, by Ernst Antevs. viii + 118 pp. Merrill & Weber Co., 1932. To be ordered from Bertha B. Smith, 28 Beacon Ave., Auburn, Me.