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Report No. 53

REPORT ON THE MINIMUM OXYGEN DEMANDS FOR VARIOUS SPECIES OF FISH

This report was prepared at the request of the Michigan Stream Control Commission.

It is unfortunate to have to report that the information on this subject is very scanty, although papers on closely related phases are rather numerous. The information imparted cannot be rendered as absolute for we are convinced that the technic employed by some of the investigators could have been improved upon. Experiments by others were too artificial and of too short a duration to be of any practical value.

Since more information was obtained on trout than on other fishes the findings on trout will be presented in order to bring out some of the difficulties encountered in arriving at any conclusion regarding the amount of oxygen in the water needed to support fish life.

Moore (1929) reports that in an eastern hatchery the water supply contained 4.4 parts of oxygen per million. The temperature of the water was 9.7°C. The brook trout which survived an _Octomitis_ epidemic made a splendid growth, but the mortality resulting from the disease was high. In the hatchery trough the water contained 6.0 parts of oxygen per million. Moore also reports that at Bath, New York the water delivered to the hatchery trough had 2.1 parts per million at a temperature of 9°C. If the trout were not taken by disease they made a good growth. Gutsell (1929) found that brook trout could stand as little oxygen as 1.2 parts per million for a short time. Gardner and Leetham (1914) have shown that a trout uses twice as much oxygen for respiration if the temperature of the water is raised from 10 to 20°C. Juday and Wagner (1908) found that lake trout commonly entered deep water with so little oxygen that they could not live long. Paton (1902) observed that brook trout kept in water with a small amount of oxygen were able to survive for some time by remaining inactive on the bottom and thus reducing their metabolism to a minimum. This author says that water with 2.8 parts per million of oxygen is fatal to young salmonoids, but he used only rainbow trout in his experiments. Gardner and Leetham (1914) found the asphyxial points for brown trout to be as follows: temperature 6.4°C – oxygen 1.13 parts per million; temperature 9.5°C to 10°C – Oxygen 1.16 parts per million; temperature 17°C – oxygen 1.96 parts per million; temperature 18°C. – oxygen 2.13 parts per million; temperature 24°C. – oxygen 2.82 parts per million; temperature 25°C. – oxygen 3.43 parts per million. Embody (1927) thinks that these figures are about right for lake trout too. He states that the asphyxial point for fish varies directly with the water temperature, therefore making the requirements of fish greater at higher temperatures. Consequently, the relation between depth and oxygen content assumes greater importance.

In natural brook trout streams, of Michigan, Creaser (1930) found the dissolved oxygen content to be 6.2 to 8.9 p.p.m. where trout were present; a value as low as 4.2 was found in one point in a trout stream where trout did not occur, and as low as 2.3 and 3.7 p.p.m. where trout are often caught though they could not be located here when the tests were made. Many tests by Powers (1929) in Tennessee brook trout streams showed 6.2 to 11.3 p.p.m.

Taking into consideration all the information available to us, we believe that trout water should contain at least 4.0 parts per million of oxygen to be considered satisfactory for existence with a margin of safety. We do not, however, have evidence to indicate that so low a value would not seriously affect the trout supply in some other way than the mere killing of the fish.

Carp according to Reighard (testimony, River Raisin pollution case) can live in water with an oxygen content of less than one part per million.

Winterstein (1908) found that one part per million of oxygen was sufficient to sustain a European cyprinid fish, Scardinius erythropthalmus.

Pearse and Achtenberg (1920) say that perch can remain below the thermocline an hour or two without suffocation and these authors claim that the fish use oxygen in the swim bladder for respiration when in stagnant water. Other authors doubt the conclusion that enough oxygen can be thus obtained to be of much significance.

Packard (1905, '07, '08) kept top minnows, Fundulus heteroclitus in oxygen free water and found that they lived about three hours.

Pearse and Achtenberg (1920) say that most fishes show signs of distress when the oxygen is from 1.43 to 5.72 parts per million. It is also stated by these authors that in natural bodies of water carbon dioxide increases as oxygen decreases but in the amounts which occur in nature the carbon dioxide is not particularly detrimental provided enough oxygen is also present.

Wells (1913) has shown that fishes are more active in water containing a scanty supply of oxygen and has demonstrated (1915) that a number of freshwater species select slightly acid water in preference to that which is alkaline. He also determined that abundant oxygen and carbon dioxide was less injurious to fishes than small amounts of both or than much carbon dioxide and a little oxygen. A quotation from Wells which may be of use: "Fish die from lack of dissolved oxygen or excess of dissolved carbon dioxide. Oxygen in large amounts (10 cc. per liter) antagonizes the detrimental effect of high carbon dioxide (50 c.c. per liter). Low oxygen (0.1 c.c. per liter) in alkaline water caused death sooner than low oxygen in slightly acid water. This suggests that the fishes have a carbon dioxide optimum. The resistance of the fishes to fatal concentrations and combinations of oxygen and carbon dioxide varies with the individual, with the species, and with the size (i.e. weight). Small fishes are more resistant per unit weight than are large ones."

Shelford (1918) gives a table showing the relative resistance of common species of fish in water of low oxygen and high carbon dioxide; trout not included. The list of fish in order of resistance from least to most is as follows: brook silversides, red-horse, sucker, small-mouth bass, large-mouth bass, white crappie, calico bass, rock bass, perch, orange-spotted sunfish, goldfish, blue-spotted sunfish, black bullhead.

According to Shelford (1914) and Wells (1913, '15) oxygen content of water over breeding grounds should be about 4c.c. per liter (5.72 parts per million) and carbon dioxide probably not more than 1 to 5 c.c. per liter.

Wells (1918) says that it is doubtful whether fish could live in water the year around where the carbon dioxide was as high as 6 c.c. per liter. Common fish in order of resistance to carbon dioxide according to Wells: (least to most ) red-horse, straw-colored minnow, blunt-nosed minnow, orange-spotted sunfish, green sunfish, black bullhead.

We are quite confident that enough material has been presented to convince the reader that saturation or near saturation of oxygen in the water is of minor significance as far as fish life is concerned. Of course, it is true that a certain percentage of oxygen is necessary and judging from our knowledge at the present time it seems that water having constantly at least 4 parts per million would be sufficient to take care of the existence needs of the majority of fishes. Whether the fishes would freely reproduce and not move out of such waters is a more difficult question.

It is quite obvious that the oxygen content is merely one isolated factor in a vast complex of conditions. How extensive is this complex at the present time cannot be told. That it makes the technic of experimentation a very difficult problem is fully realized.

We are accumulating some evidence to indicate that it is detrimental to change abruptly some species of fish from water supersaturated with oxygen to water not so well oxygenated but containing a sufficiency to take care of fish which have not been subjected to an abrupt change. It is possible that a danger to fish life exists in the relatively rapid changes in oxygen content in highly polluted waters, which may vary in oxygen-content from a high supersaturation in bright sunlight to a marked deficiency at night.

This great diurnal variation in oxygen content of polluted waters makes it difficult to obtain an accurate figure for the lowest oxygen level reached. The tendency of lowest values to occur at nights, especially following cloudy days, when tests usually are not made, causes the recorded values to be usually higher than the actual oxygen minima occurring in the streams.

The difficulty of being on the stream when the oxygen is lowest is due not only to this diurnal variation, but also to seasonal variations in stream flow, stream temperature, activities of polluting agencies, etc. The variations in polluting agencies may be very sudden of course, as during "clean-outs", or breaks in settling basins.

Further difficulties in arriving at any evaluation of the effects of pollution on fish life may be enumerated -

(1) Other polluting substances than the oxygen-consuming may be involved - either in directly affecting the fish or in modifying the oxygen requirement.

(2) The pollution may remove desirable fish while allowing coarse fish to remain or even increase. Evidence can be cited to support this point.

(3) Fish react negatively to polluted water that does not kill them, and thus vacate polluted portions of streams.

(4) Bacterial diseases have been observed by us to flourish in polluted waters - especially the fin-consuming organisms.

(5) Worm diseases may be expected to increase in polluted waters which cause a great increase in the population of snails which act as the hosts of parasites which in a later stage attack fishes.

(6) Pollution may have an affect on growth rate, causing some species to grow faster on account of richer food, and causing others to grow more slowly. We have found the carp of the polluted part of the lower River Raisin to grow

much more slowly and to reach a much smaller size than in the cleaner waters above Monroe.

(7) Polluted water that will not kill the adults may kill the young, or more likely kill the spawn or sperm of the fish.

(8) Many pollutions produce bottom deposits unfavorable to fishes, especially from the standpoint of breeding.

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SUPPLEMENT TO REPORT NO. 53

ON THE MINIMUM OXYGEN DEMAND FOR VARIOUS SPECIES OF FISH

From a series of experiments on the minimum oxygen demand for fish, conducted under laboratory conditions, we have obtained some information which is, perhaps, of interest to The Stream Control Commission. If nothing else it empahsized the immensity and complexity of this problem.

Running, iron-free water with a temperature ranging from 12°C., to 13°C., was used in these experiments. Aquaria with a capacity of 46 liters were used for containers and fitted with screen placed below the surface of the water so that the fish could not get to the surface. The supply of water to the aquaria was constant for each and regulated by gravity siphons. The water was dropped into a metal pipe which reached to near the bottom of the aquarium to insure circulation. The water was oxygenated by natural means, by dropping it varying distances to obtain the desired amount of oxygen. Numerous tests of water from various parts of the aquarium and at different depths showed the oxygen supply to be surprisingly constant.

In the following experiment fish were transferred from water containing 8.0 p.p.m. of oxygen to water containing 2.0 p.p.m. and left for 24 hours, then transferred to water with 1.0 p.p.m. of oxygen. The temperature at the time the fish were placed in the aquarium was 12°C. The water during the experiment was added to the aquarium at the rate of 820 cc. per minute. The experiment was continued for 9 days during which the oxygen in the water varied from o.9 p.p.m. to 1.3 p.p.m.,(the highest value was reported for one day only, near the close of the experiment;) aside from that one there was no determination higher than 1.0 p.p.m.

None of the fish died when transferred to the water containing 2.0 p.p.m. but the following died in 24 hours after being transferred to the water containing 1.0 p.p.m.; Campostoma anomalum (stone roller), male, 127 mm., Poecilichthys coeruleus (rainbow darter), males, 57 and 50 mm., females 50 and 45 mm., Chrosomus erythrogaster (red-bellied dace) female, 65 mm., Rhynichthys atronasus meleagris (black-nosed dace) female, 51 mm.

The following fish lived and showed no signs of distress; Micropterus salmoides (large-mouth bass) 105 mm., Somotilus acromaculatus (creek chub) 54 mm., Esox vermiculatus (mud pickerel) 120 and 170 mm., Ambloplites rupestris (rock bass) 92 mm., Perca flavescens (perch) 71 mm., Cyprinus carpio (carp) 64 mm., Catostomus commersonii (common sucker) 230 mm., Eupomotis gibbosus (pumpkin-seed) 79 mm., Cottus bairdii (muddler) [illegible]8 and 46 mm., Umbra limi (mud minnow) 66 mm., Poecilichthys coeruleus (rainbow darter) 54 mm.(breeding male).

It will be noted, from the foregoing lists that only one out of the five rainbow darters lived. We have tried to transfer numerous other rainbow darters the same way but have not succeeded in getting any of them to live. By trying additional individuals of Cottus we found that the smaller ones lived but the large mature specimens always died.

In the following experiment the fish were kept under the same conditions as the ones given in the previous experiment but the rate of flow of water was 775 c.c. per minute and the amount of oxygen carried from 1.9 p.p.m. to 2.2.p.p.m. The experiment was continued for 7 days. Twenty-two fish were added to the aquarium when it had an oxygen content of 1.9 p.p.m. from an aquarium containing water with an oxygen content of 8.0 p.p.m. The followin fish were used; Campostoma anomalums(stone roller) 50 mm., Somotilus atromaculatus (creek chub) 57 and 52 mm., Rhynichthys atronasus meleagris (black-nosed dace) 68, 67, 57, 57, 52, 41, 38 mm., Esox vermiculatus (mud pickerel) 164 mm., Eupomotis gibbosus (pumpkin-seed) 82 and 96 mm., Cottus bairdii (muddler) 72, 66, 47, 45 mm., Poecilichthys coeruleus (rainbow darter) 50, 50, 42, 38, 31 mm.

All of the fish lived and showed no signs of being inconvenienced by lack of oxygen except Cottus and Poecilichthys during the first twenty-four hours.

In the following experiment fish were transferred directly from an aquarium containing water with an oxygen content of 10.0 p.p.m. and temperature of 13°C. to an aquarium of water containing 0.9 p.p.m. and having a temperature of 12.5 C. Rate of flow of water into the aquarium was 820 c.c. per minute. The experiment was continued for 24 hours. At the end of that time the following fish were dead; Cottus bairdii (muddler) 70 and 45 mm., Micropterus salmoides (large-mouth bass) 74 mm., Perca flavescens (perch) 60 mm., Notropis heterodon (black-chin shiner) 50 mm., Rhynichthys atromasus meleagris (black-nosed dace) 46 mm., All showed signs of distress immediately after transfer. The following fish lived and of these only the common sucker showed signs of distress: Esox vermiculatus (mud pickerel) 108 mm., Catostomus commersonii (common sucker) 102 mm., Eupomotis gibbosus (pumpkin-seed) 70 mm., Erimyzon sucetta kennerlie (lake chub sucker) 57 mm.

From these experiments we conclude that most non-salmonoid Michigan fishes can probably endure, for at least short periods, water with as little as 2 p.p.m. of dissolved oxygen, but that most of them are killed by water with 1 p.p.m. of dissolved oxygen. The experiments do not prove that water with 2 p.p.m. of oxygen may not kill the same fish over a longer period and certainly do not prove that such water will be normally occupied by such fish, for they may swim away from such water in nature.

Nor does this report apply to trout or other salmonoid fishes. Some experiments have also been made on the cold-water fishes but these will not be reported upon until a further occasion.

These experiments were performed and the report prepared by Dr. W. H. Krull, Fish Pathologist. Report prepared for Stream Control Commission.

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