INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT

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ORIGIN AND TREATMENT OF A SUPERSATURATED RIVER WATER

BY

H. H. HARVEY and A. C. COOPER

NEW WESTMINSTER, B. C.
CANADA
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the Sockeye and Pink Salmon Fisheries in
the Fraser River System

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ABSTRACT

A small stream, Corbold Creek, has been investigated as to the cause of supersaturation of the water. Oxygen and nitrogen varied between 98 and 120 per cent of air saturation, saturation increasing with increasing discharge. The excess gas was found to enter solution in the plunge basins at the bases of the falls. Two methods of treatment were tested in order to render the water suitable for hatchery use. The effects of supersaturated water on young salmon are described. A review of the rather considerable European literature is included.

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INTRODUCTION

The decline of the sockeye salmon run to the Upper Pitt River area prompted an investigation into the suitability of a hatchery to augment natural spawning (Internat. Pacific Salmon Fish. Comm., 1961). The only readily available water supply for a hatchery in the Area was a stream, Corbold Creek (locally Seven-Mile Creek), which enters the Upper Pitt River some seven miles north of its mouth. Corbold Creek showed a steep gradient and was marked by numerous falls and rapids. This raised the question of possible supersaturation of the water in the stream, as has been shown by several workers in northern Europe. Investigation revealed that the stream was in fact supersaturated and several methods of treatment were tested in order to render the creek water suitable for hatchery use. This report summarizes the stream investigations, the methods of water treatment and the effects of the supersaturated water on sockeye alevins and fry. In view of the limited attention that this river saturation problem has received in North America, a review of the literature is included.

PREVIOUS INVESTIGATIONS

The supersaturation of river water by means of falls and rapids has received considerable attention in northern Europe. Järnefelt observed oxygen supersaturation on the River Vuoksi (eastern Finland) but his publications of 1928 and 1936 in Finnish biological and chemical periodicals appear to have escaped notice. Järnefelt (1948) summarized his earlier studies and clearly implicated rapids and hydroelectric installations as the cause of variation in saturation of Vuoksi water. Below the falls at Imatra, Järnefelt found oxygen as high as 137 per cent of air saturation. Wiken (1936) investigated the saturation of lake surface water and distinguished between biogenic or biological changes and abiogenic or physical changes in oxygen saturation. Schmassmann (1951) reported extreme variation on the River Birs (northern Switzerland), ranging from a low of 70 per cent at night to a high of 280 per cent during the day, as a result of photosynthetic processes. Ebëling (1954) and Höll (1955) also observed supersaturation of stream water, Höll recording saturations of as high as 129 per cent on the Urselbach, (Germany) a relatively small stream of moderate gradient but with falls and rapids.

Mortimer (1956) in discussing standards of saturation noted the possibility that bubbling or violent agitation in nature, such as rapid stream flow, might result in supersaturated water which reached equilibrium slowly. That this took place was shown by Lindroth (1957) who reported on the studies of the Indalsälven River of Sweden, including those of Andren and Carlsson. Lindroth offered an explanation of the mechanism by which the river water exceeded air saturation: "In waterfalls the water is mixed with air bubbles of different sizes. These bubbles are carried to various depths, according to the topography of the river (especially at the foot of the fall) and to flow conditions, and give part of their gases off to the water, following physical laws, under the increased pressure before rising to the surface."

METHODS

Oxygen content of the water was determined by the Winkler procedure as described in Standard Methods for the Examination of Water and Wastewater. Routinely two samples were analyzed consecutively and the oxygen content expressed as an average. Thiosulfate was standardized periodically and corrected to within ± 1 per cent. Analysis of dissolved nitrogen was based on the technique of Scholander, Van Dam, Claff and Kanwisher (1955). The procedure was modified somewhat for field use (Harvey, 1961) and ten determinations on air-equilibrated water yielded an average of 100.5 per cent of air saturation with ± 2.1 per cent for one standard deviation. Because of the reduced accuracy of the nitrogen method, five or ten determinations were performed at each test condition and the results averaged.

THEORETICAL SOLUBILITIES

Oxygen or nitrogen per cent of saturation is based on gas measured in solution in relation to its solubility in air-equilibrated water at a given temperature and pressure. In this study the theoretical oxygen and nitrogen values were calculated on the basis of the absorption (Bunsen) coefficients and an atmosphere of 20.95 per cent oxygen and 79.05 per cent nitrogen. The absorption coefficients were taken from the Handbook of Chemistry and Physics and are essentially those of the 1955 International Critical Tables.

Recently Truesdale, Downing and Lowden (1955) have published oxygen solubilities as much as 3 per cent below the generally accepted values. Elmore and Hayes (1960) also redetermined oxygen solubilities and concluded the values given in Standard Methods were substantially correct from 0 to 5°C but were slightly high between 10 and 30°C. Morris, Stumm and Galal (1961) concurrently redetermined oxygen solubility and found close agreement with Elmore and Hayes. Morris *et al*. pointed out that absolute percentage saturation with dissolved oxygen of any sample cannot be given to better than 1 per cent and currently values of 0.1 per cent of saturation are not significant. Hart and Downing (1961) attributed a part of the difference between measured oxygen solubilities to the different analytical procedures used.

In the case of nitrogen, the solubilities determined by Fox (1909) have been in general acceptance ever since. Rakestraw and Emmel (1938) and Morrison and Billet (1948) have reported solubilities 2 to 3 per cent below these values. In view of the limitations of the methods and the uncertainty of the theoretical solubilities, the percentage saturations should not be interpreted as being correct, at best, to more than ± 1 per cent for oxygen and ± 2 per cent for nitrogen in this study.

STREAM STUDY

Corbold Creek is a stream of steep gradient coursing within a deep gorge cut through the granodiorite of the Coast Range Mountains. The stream is in effect a series of falls and rapids. At the base of many of the falls are deep plunge basins. Gas analysis performed at intervals along the length of the stream indicated the water was alternately tending to supersaturation or air-equilibration. Freely falling water tended to air-equilibrate and this tendency was enhanced further if the falling water impinged on rocks at the base of the falls. The 80 foot high falls shown in FIGURE 1, for example, reduced oxygen saturation from 108 per cent to 106 per cent at one level of stream discharge and from 108per cent to 105 per cent at a lesser stream flow. In the case of this falls, the water drops freely onto a rock shelf at the base of the falls.

Falls with deep plunge basins raised saturation values by means of entrained air carried to depth and additional air being forced into solution at the higher pressure. A low falls (FIGURE 2) varying in height from 10 to 20

FIGURE 1. A high falls on Corbold Creek impinging on a rock shelf at the base and tending to air-equilibrate stream water.

FIGURE 2. A low falls on Corbold Creek with a deep plunge basin and tending to supersaturate stream water.

feet depending on discharge, markedly increased oxygen and nitrogen saturations. At relatively low discharge oxygen saturation was raised from 106 to 110 per cent, at moderate discharge from 113 to 121 per cent and at high stream flow from 116 to 122 per cent.

Oxygen saturation and stream discharge were measured periodically during 1960 and 1961 on Corbold Creek at the site of the hatchery supply intake. In general, saturation increased with increasing discharge (FIGURE 3). At higher discharges, plunge basins deepened, air-equilibrating rapids were often flooded out, rocks at the bases of falls were more commonly under water and turbulence within the stream was increased. Considerable variation was found in saturation at any level of discharge. Only a small portion of this variation is attributed to the technique of oxygen determination. A considerable amount of variation was found during the course of the same day and with the level of discharge constant. This may be the result of changes in barometric pressure and in stream temperature during the day. There was also some evidence of seasonal variation, possibly resulting from the stream originating principally at lower elevations during winter.

On leaving the rock gorge described previously, Corbold Creek enters the flat valley of the Pitt River and becomes a shallow stream coursing over gravel and boulders. The supersaturated water was sufficiently stable that oxygen saturation only declined from 110 to 105 per cent along the one-half mile that the stream ran to its confluence with the Pitt River.

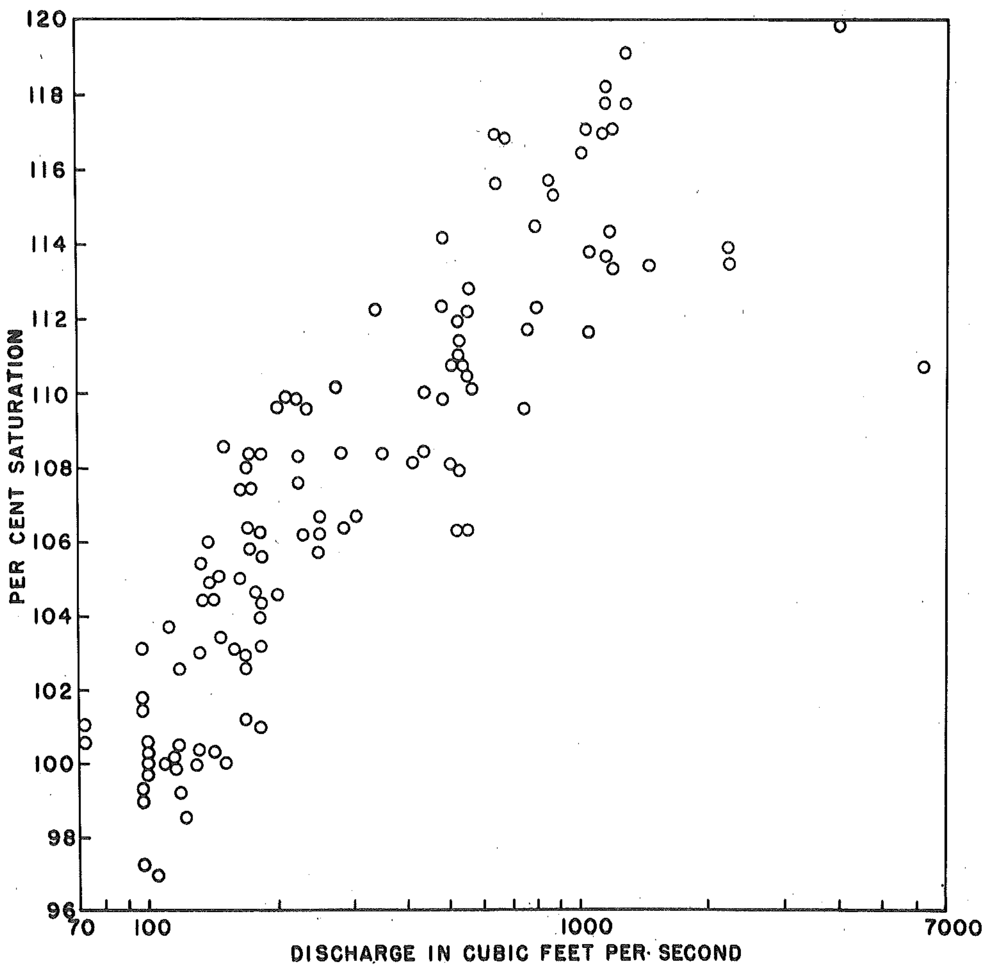

FIGURE 3. Oxygen saturation in relation to stream discharge at the point of the hatchery intake, Corbold Creek.

TREATMENT

The problem of utilizing supersaturated water has been reported in the past by Rucker and Tuttle (1948), Rucker and Hodgeboom (1953) and Erdman (1961). Air-equilibration of Corbold Creek water was attempted initially by jetting the supersaturated water into a blind box (FIGURE 4) which resulted in a frothing mixture of air and water. At high levels of stream saturation this method reduces oxygen content to approximately 106 per cent of air saturation. In view of the limitations of this apparatus, it was replaced by a 4 foot square tower 20 feet high (FIGURE 5). In this structure, water was fed to the top under gravity and permitted to cascade down over a series of baffles set at right angles. Analysis indicated dissolved oxygen was reduced to 99 per cent of air saturation and nitrogen to approximately 102 per cent over a range of stream saturations of 100 to 115 per cent. The results of six tests of the tower with flows ranging from 7.1 to 33.8 U.S. gallons per minute per square foot of tower cross section are shown in FIGURE 6. It was found, for the conditions shown, that a fall of 13.5 feet through 13 baffles was sufficient to reduce the oxygen and nitrogen concentrations to very close to air saturation. The data indicated a tendency to greater gas removal at the higher flows tested but the range of results was too narrow to determine if there is an optimum flow.

OXYGEN : NITROGEN RATIO

Oxygen saturation levels were determined routinely by the Winkler method as described. Accurate analysis for dissolved nitrogen, being much more difficult and time consuming, was limited to periodic checks. In general oxygen and nitrogen saturations of the stream water agreed closely but with

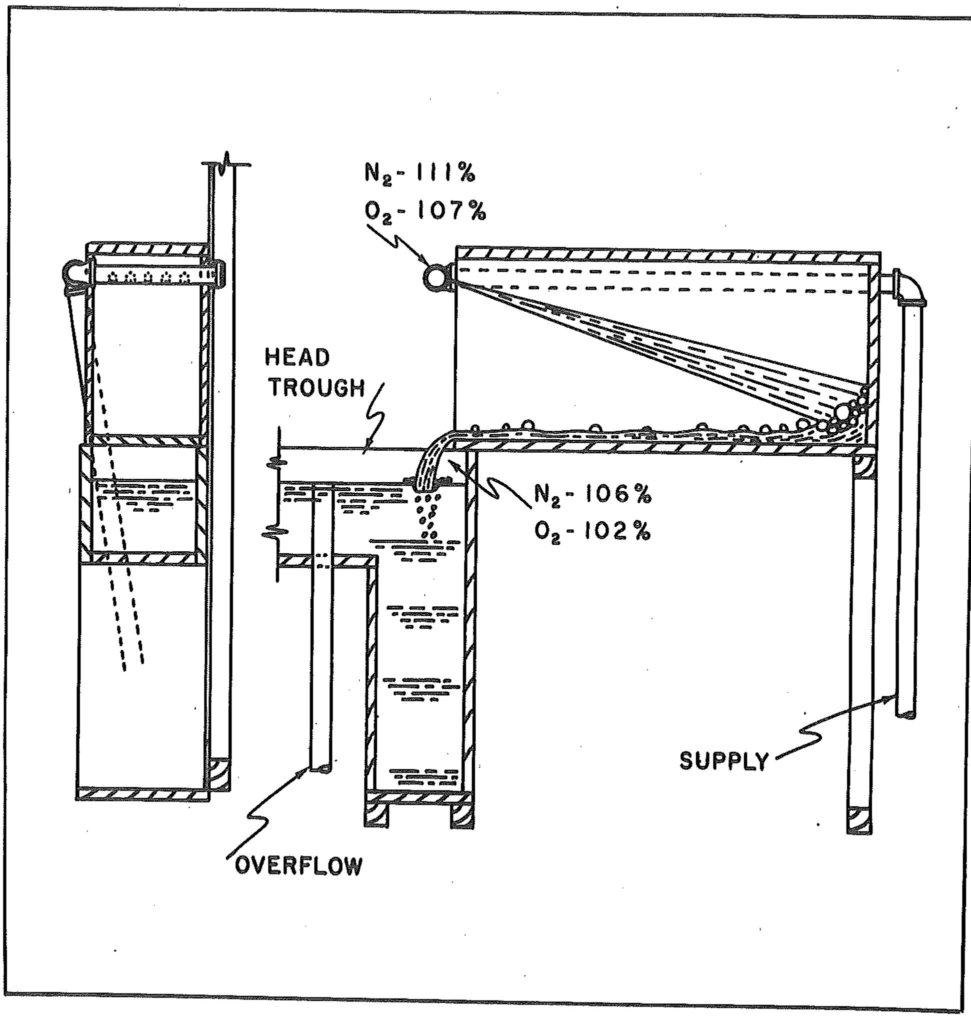

FIGURE 4. Original apparatus tested for affecting air-equilibration of supersaturated stream water.

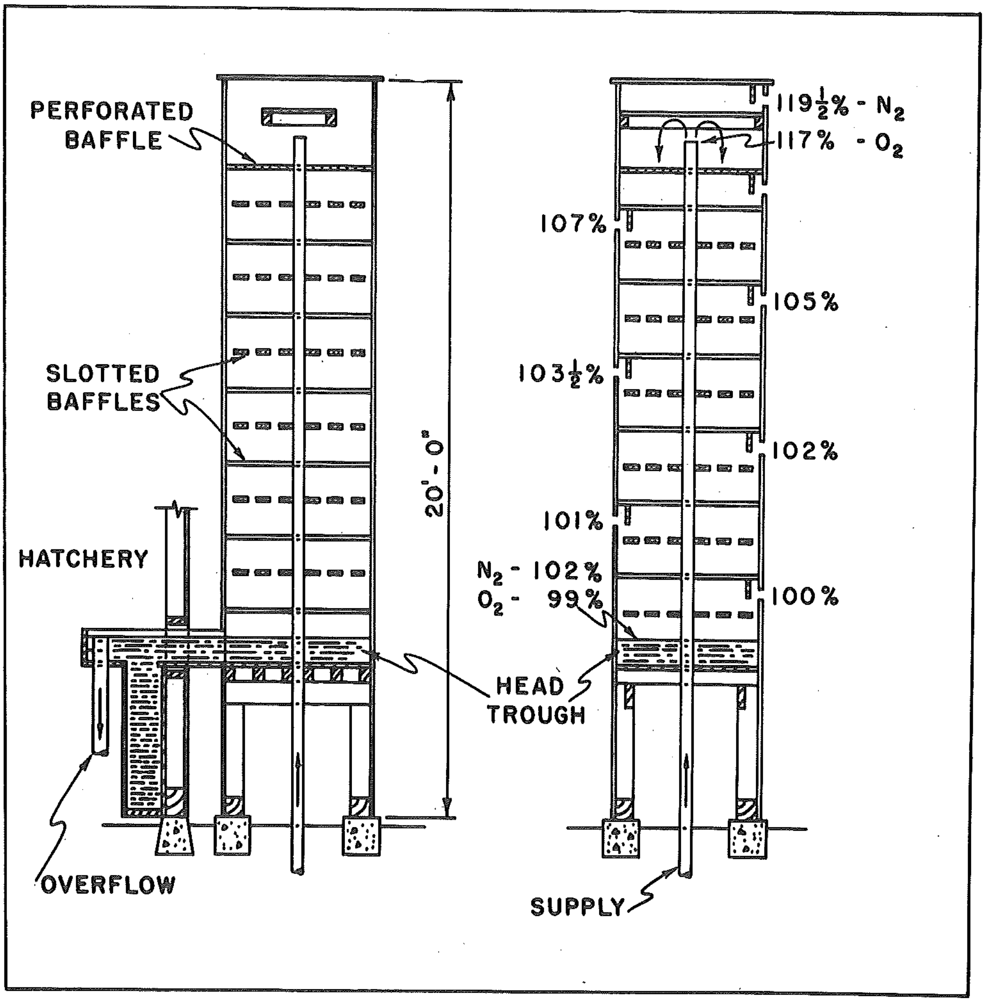

FIGURE 5. Highly effective air-equilibrating tower in which stream oxygen and nitrogen are reduced to within one or two per cent of air saturation.

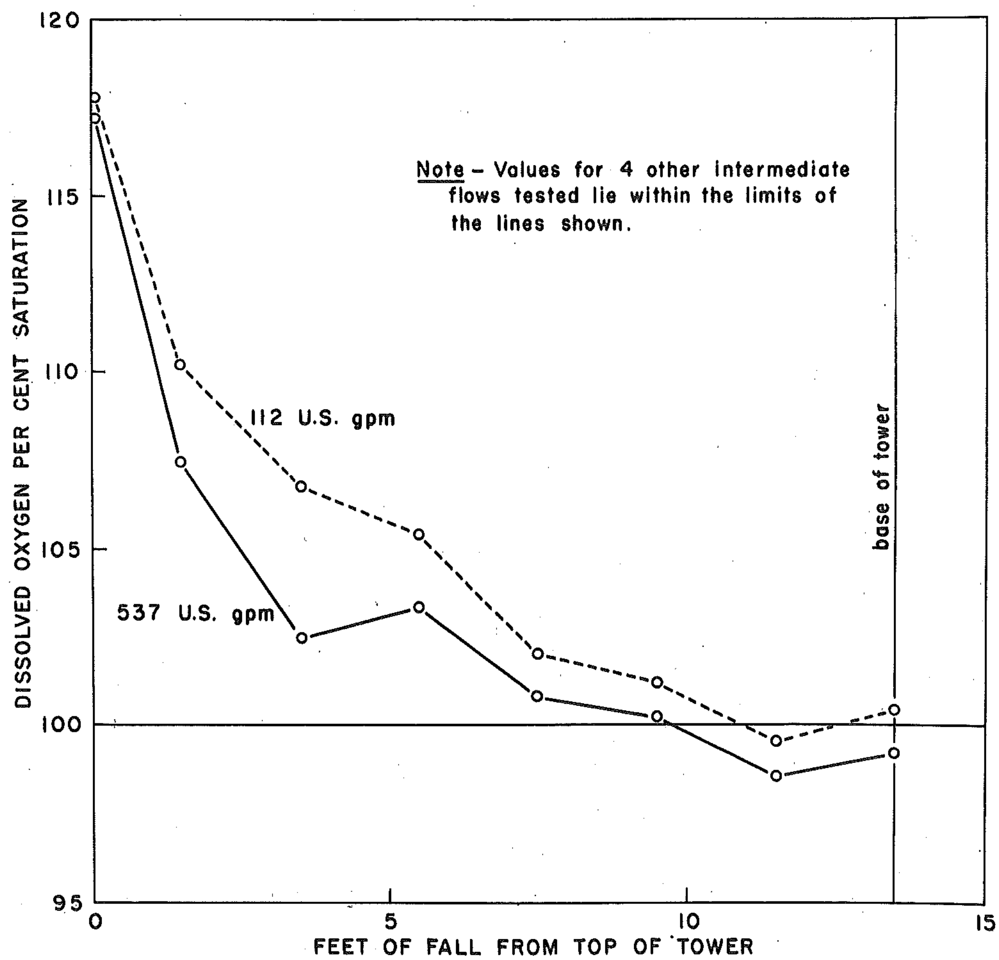

FIGURE 6. Relation between fall and flow in tower and reduction in oxygen saturation.

nitrogen saturation approximately 2 to 4 per cent above that measured for oxygen.

Gases enter solution in relation to the products of their partial pressures and solubilities. Oxygen is twice as soluble in water as nitrogen, but in air has only one-quarter of its partial pressure and hence in air-equilibrated water oxygen has approximately one-half the concentration of nitrogen. Under the increased pressure at depth in the stream, the oxygen and nitrogen in air bubbles should continue to enter solution in this same ratio, provided the composition of the gas phase (bubbles) does not change. In the case of air bubbles entering solution completely, nitrogen would enter solution four times as plentifully as oxygen, instead of twice as readily as under surface or atmospheric conditions, and nitrogen saturation would tend to exceed that of oxygen.

Oxygen : nitrogen imbalance could also be brought about by small bubbles of air entering solution only partially. Under increased pressure, oxygen and nitrogen will enter solution in relation to the products of their partial pressures and solubilities, leaving behind a gas phase (bubbles) of progressively higher nitrogen content. This increase in the partial pressure of nitrogen within the bubbles would result in a progressively higher nitrogen fraction entering solution. Thus there is a theoretical basis for the slightly higher nitrogen saturations measured in the stream water. Harvey and Smith (1961) observed this phenomenon in the case of air entering a hatchery pipeline.

EFFECT ON FISH

The effects of supersaturated water on fish are well known to fish culturists. The literature has been reviewed recently by Bishai (1960) and by

Harvey and Smith (1961). However, a number of basic questions remain unanswered. There is the tendency of fish to equilibrate internally with the dissolved nitrogen of the environment (Harvey, unpub.). If the water medium is supersaturated there is a subsequent tendency for gases to leave solution within the fish (Egusa, 1959). Alevins appear to be particularly susceptible to this process. In the present study a single hatchery trough was supplied with untreated stream water in order to observe the effects of the high gas tensions on the fish. Five thousand eggs were incubated in this water and the resulting alevins developed symptoms of gas disease following five days of exposure to water varying between 108 and 120 per cent of air saturation. Gas accumulated rapidly within the yolk sac (FIGURE 7) and consisted of an average of 17 per cent oxygen and 83 per cent nitrogen. Nitrogen supersaturation is blamed for most instances of gas disease in fish. However, it should be remembered that gases enter and leave solution in relation to their partial pressures and solubilities and hence bubble growth involves both oxygen and nitrogen and in the case of decompression-induced embolisms, possibly carbon dioxide (Harris et. al., 1945).

Recently Bishai (1961) has reported herring larvae were able to live in supersaturated water without ill effect. In his experiment however, while the saturation was 120 per cent of atmospheric pressure, the young herring were held five days at a pressure of two to four atmospheres and hence the gas content was well below saturation. The larvae would tend to equilibrate internally with the dissolved nitrogen of the water but there would be no tendency for gas to leave solution and form bubbles within the fish as is the case with holding fish in water supersaturated at atmospheric pressure.

Sockeye alevins held in water which had passed through the original air-

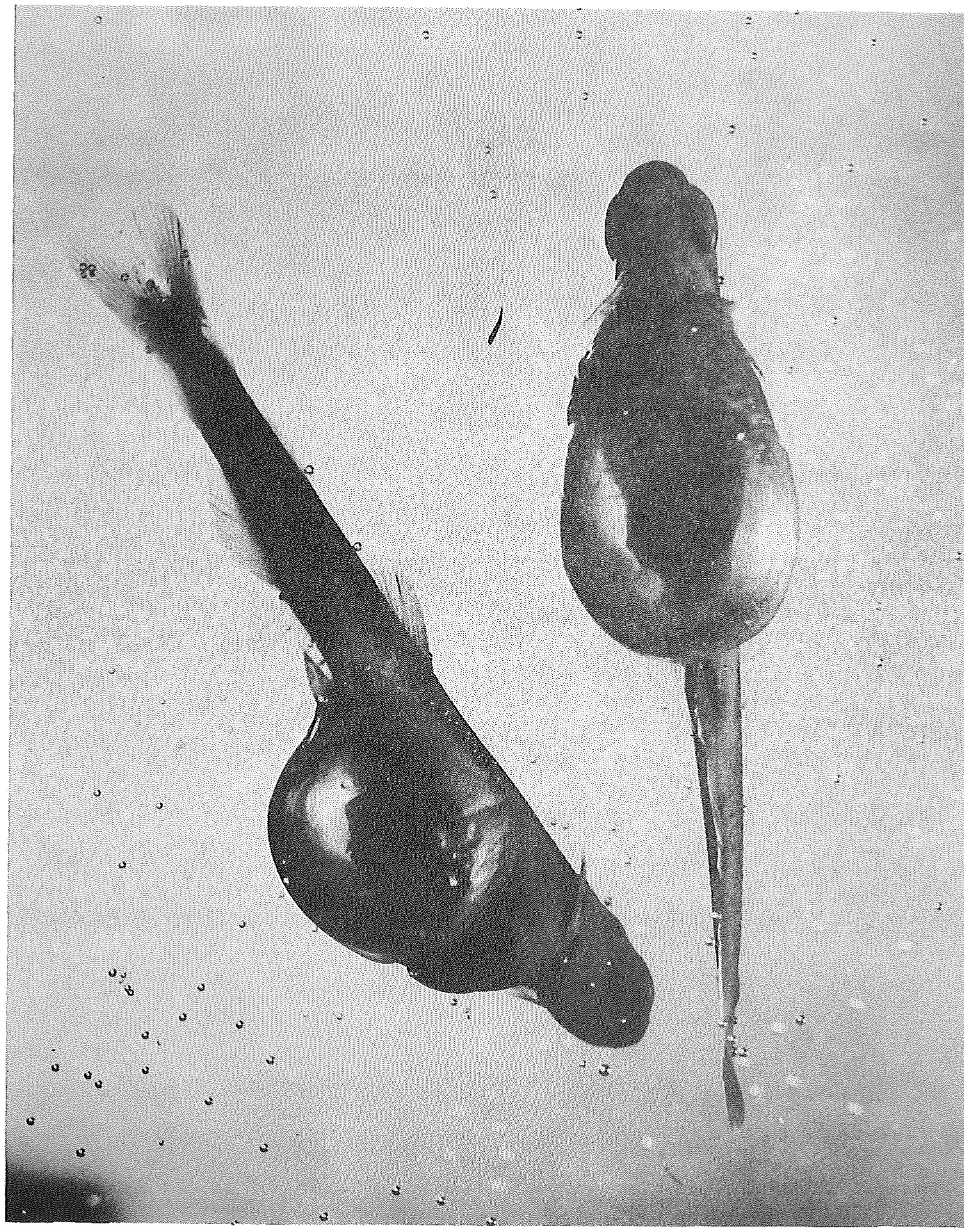

FIGURE 7. Sockeye fry, yolk sacs distended by large bubbles of nitrogen and oxygen. Note: Minute bubbles on fish and in the water have resulted from flood-lights heating the water during photography.

equilibrating apparatus (FIGURE 4) showed some evidence of gas disease even though oxygen saturations did not exceed 106 per cent of air saturation. Mortalities were approximately 2 per cent at this low saturation as compared to 20 per cent among alevins exposed to the high gas levels. As the surviving alevins developed into fry, a variety of injuries became apparent, including petechial hemorrhages, necrotic areas on the fins, protruding and hemorrhagic eyes and fish bloated with fluid in the yolk sac or under the skin. It is believed that these injuries were initiated by gas bubbles forming in the respective tissues. Again such injuries were much more common among alevins held at the higher gas levels. In the second year of hatchery operation, the injuries and mortalities described above did not occur when the water supply was passed through the improved air-equilibrating apparatus. The sockeye left the hatchery as fry and the study of gas disease was terminated at this stage.

Annually, several hundred to several thousand sockeye spawn in the half mile of Corbold Creek extending upstream from its confluence with the Upper Pitt River. Sampling of spawning nests has shown that in spite of the existence of supersaturated water in the surface flow, alevins survive to the fry stage within the stream gravel. The lack of mortality of alevins under conditions of supersaturation is attributed to a number of factors acting to reduce gas saturation of the water: The saturation of the stream declines gradually along its length. The hydrostatic head tends to hold air in solution, for example at a depth of 2 feet saturation would be reduced 7 per cent. The rate of water percolation through the gravel is relatively slow and some reduction in saturation may result from mixing of water below the gravel surface. Oxygen utilization within the stream gravel would tend to reduce the total gas partial pressure. There was some evidence of air coming out of solution on the surface of rocks and stones and hence the gravel may tend to remove excess gas from solution by providing a surface on which bubbles can grow.

SUMMARY

1. A case of river water supersaturation is described and discussed in relation to the pertinent literature.

2. A distinction is made between physical (abiogenic) and biological (biogenic) oxygen supersaturation of natural waters. The former, being accompanied by nitrogen supersaturation, rapidly induces gas bubble disease in fish, whereas the latter has deleterious effects on fish only at very high oxygen tensions.

3. In certain instances there may be little doubt as to whether supersaturation results from photosynthesis or through falls and rapids. However in doubtful cases, diagnosis of stream supersaturation by means of dissolved oxygen determinations must be accompanied by dissolved nitrogen analysis or oxygen sampling must extend over the period of maximum and minimum photosynthetic activity.

4. Two methods of treatment of supersaturated water are evaluated. A highly effective air-equilibrating tower is described.

5. The injuries and mortalities appearing among sockeye alevins and fry which were exposed to high (120 per cent of air saturation) and low (106 per cent)levels of supersaturated water are reported.

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