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SOME EFFECTS OF CONTROLLED LEVELS OF DISSOLVED GAS SUPERSATURATION ON SELECTED SALMONIDS AND OTHER FISHES

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Some Effects of Controlled Levels of Dissolved Gas Supersaturation on Selected Salmonids and Other Fishes

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ABSTRACT

Fish cultural problems associated with gas supersaturation are discussed. Four species of salmonids and four warm-water species were exposed to various levels of gas supersaturation in a controlled experiment to determine lethal levels and sublethal effects. A twin-piston water pump fitted with an inlet for introduction of an oxygen-nitrogen gas mixture, coupled with a forty-foot residence chamber with gate valve, allowed production of supersaturated water with a relatively constant nitrogen content.

High levels produced mortality and eye damage in salmonids; especially hemorrhaging, popeye, and corneal cataract. A possible method of corneal cataract formation is discussed. Necropsies indicated the cause of death at high total gas levels to be massive air emboli in major blood vessels and the heart. Sublethal effects are more difficult to assess, but a lowered growth rate, general decreased resistance to common hatchery diseases and corneal cataract are indicated.

INTRODUCTION

Gas bubble disease of fish resulting from water supersaturated with air has been known for many years (Marsh and Gorham, 1905; Rucker, 1972) and has been a problem in hatcheries (Harvey and Smith, 1961; Wood, 1968) and in streams of the Pacific Northwest (Beiningen and Ebel, 1970; Ebel, 1969). Water becomes supersaturated with gas due to changes in pressure or temperature. Gas concentrations in the fishes' blood equilibrate with those of the water and gas bubbles are formed and accumulate in the circulatory system.

Gas supersaturation and gas bubble disease have recently been diagnosed in Minnesota and apparently have appeared irregularly for some time. In Minnesota, problems from gas supersaturation have resulted from the use of supersaturated spring and well water for salmonid culture, and from heating saturated water to decrease hatching time of walleye and muskellunge eggs.

Lethal levels of gas supersaturation have been determined for several species (Beiningen and Ebel, 1970; Egusa, 1969; Wood, 1968). In recent years, effects of sublethal gas supersaturation levels have been investigated (Poston et al, 1973; Schiewe, 1974). Preliminary work at the Lanesboro State Fish Hatchery indicated that sublethal levels of gas supersaturation were influencing the production performance of some salmonids.

A simple laboratory system was designed to deliver a controlled flow of gas supersaturated water. This system was used to determine lethal levels of gas supersaturation and the effects of sublethal levels of gas supersaturation on several species of salmonids and several warm-water species.

MATERIALS AND METHODS

The laboratory system used to deliver a controlled flow of gas supersaturated water is shown in Figure 1. Temperature of the well-water supply was 10° C; saturation values of dissolved oxygen and total gas averaged 84% and 101%, respectively. The positive displacement, twin-piston water pump (Hypro Series 5300) could pump up to 2.5 gpm at 500 psi. A needle valve at the pump outlet metered the incoming gas from a cylinder of premixed nitrogen and oxygen. The desired levels of nitrogen supersaturation and acceptable levels of dissolved oxygen were achieved by gas mixtures of 85% N_2-15% O_2 or 90% N_2-10% O_2. A forty-foot delivery system fabricated from three-inch plastic piping also served as a residence chamber to allow time for equilibration of water and gas under pressure. Back pressure throughout the system was maintained by restricting the flow with a globe needle valve at the end of the chamber. Fish were held in fifty-gallon flow-through tanks with 26 gallons of water. This apparatus could produce about 300% gas supersaturation.

Total dissolved gas and dissolved oxygen concentrations were monitored with a Weiss saturometer and oxygen probe, respectively. Water temperature and atmospheric pressure were routinely recorded. Fickeisen et.al. (1975) found that results of the saturometer did not differ significantly from those of gas chromatography. Experimental and control lots each contained 25 fish unless otherwise noted. Experimental lots were generally used for only one test. Exceptions are explained later. The standard exposure time was seven hours.

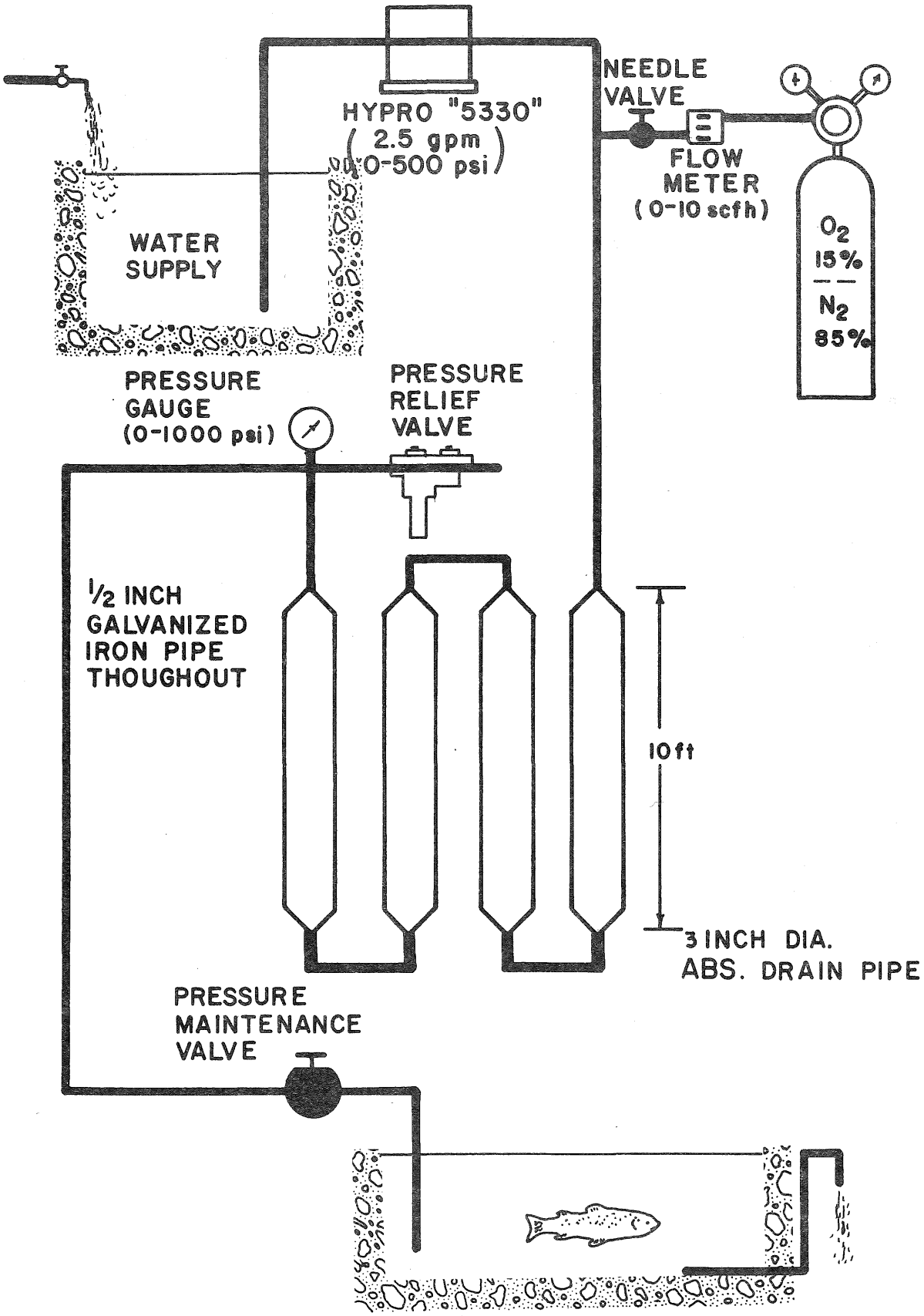

Figure 1. Apparatus used to produce supersaturated concentrations of nitrogen gas in water.

Results will be reported as total gas supersaturation. Early studies reported only nitrogen supersaturation levels. Nitrogen saturation values are slightly greater than those for total gas because of the greater solubility of nitrogen. Figure 2 compares total gas and nitrogen saturation values for this experiment.

RESULTS

In general, some mortality of salmonids was noted after seven hours of exposure to 120% total gas saturation (Figure 3). Death was attributed to gas bubbles within the heart or circulatory system, particularly the post-caval vein, impeding circulation to the heart.

Common gas-bubble disease symptoms of salmonids which were observed include: formation of bubbles on the fish, hemorrhaging, eye damage, and internal damage. Points of bubble formation were skin, fins, under the skin and behind the eye. Eye damage included hemorrhaging, popeye, and corneal cataract.

Chronic sublethal levels of gas supersaturation appeared to act as a stress factor. Effects at these lower levels were difficult to assess but growth, diet efficiency, and resistance to general hatchery diseases appeared to be reduced.

Resistance to gas supersaturation among the warm-water species tested varied considerably. In addition to the symptoms noted in salmonids, affected fish would float on the surface, often on one side, with head down, indicating over-inflation of the gas bladder.

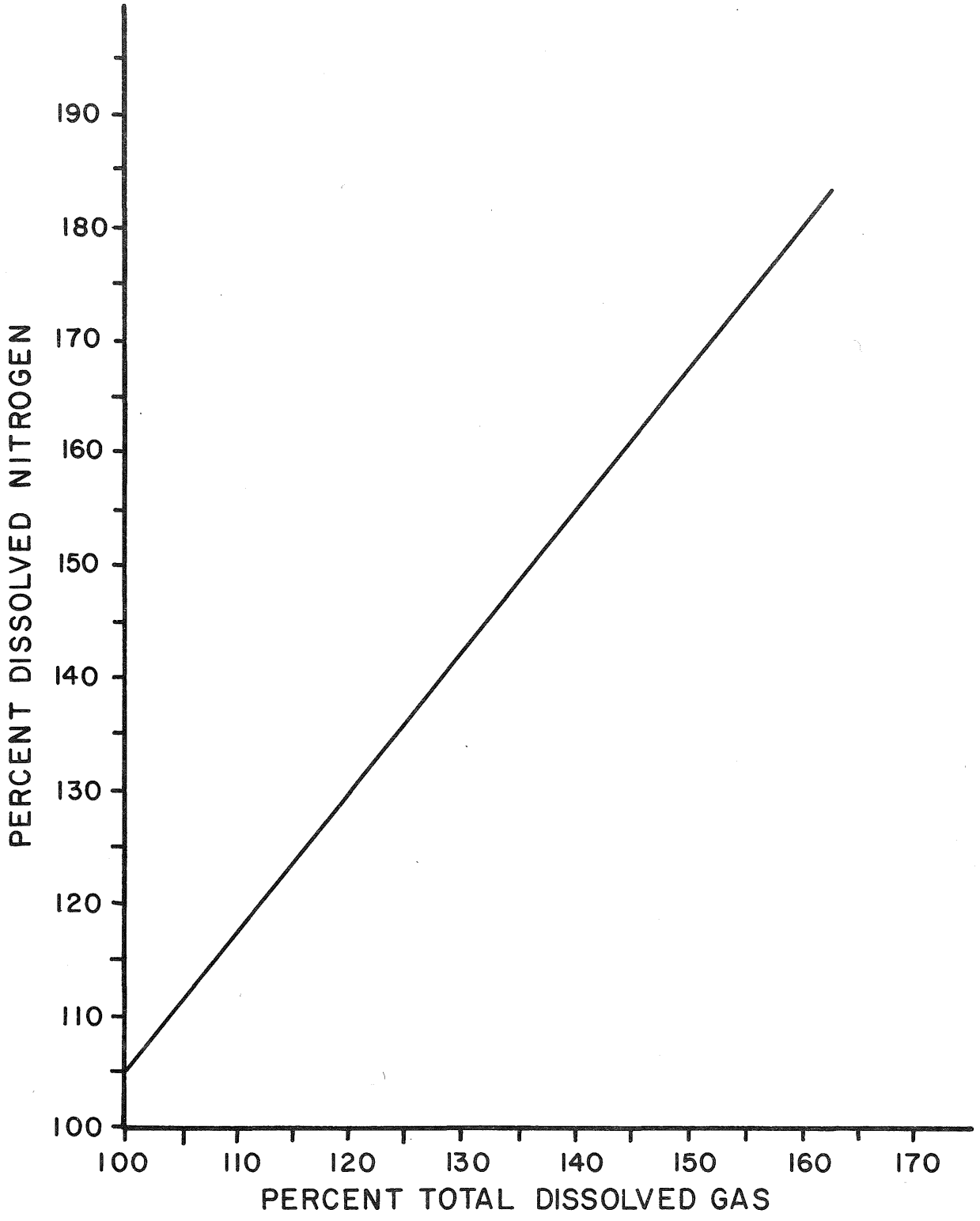

Figure 2. Relationship of dissolved nitrogen to total dissolved gas at the St. Paul State Fish Hatchery.

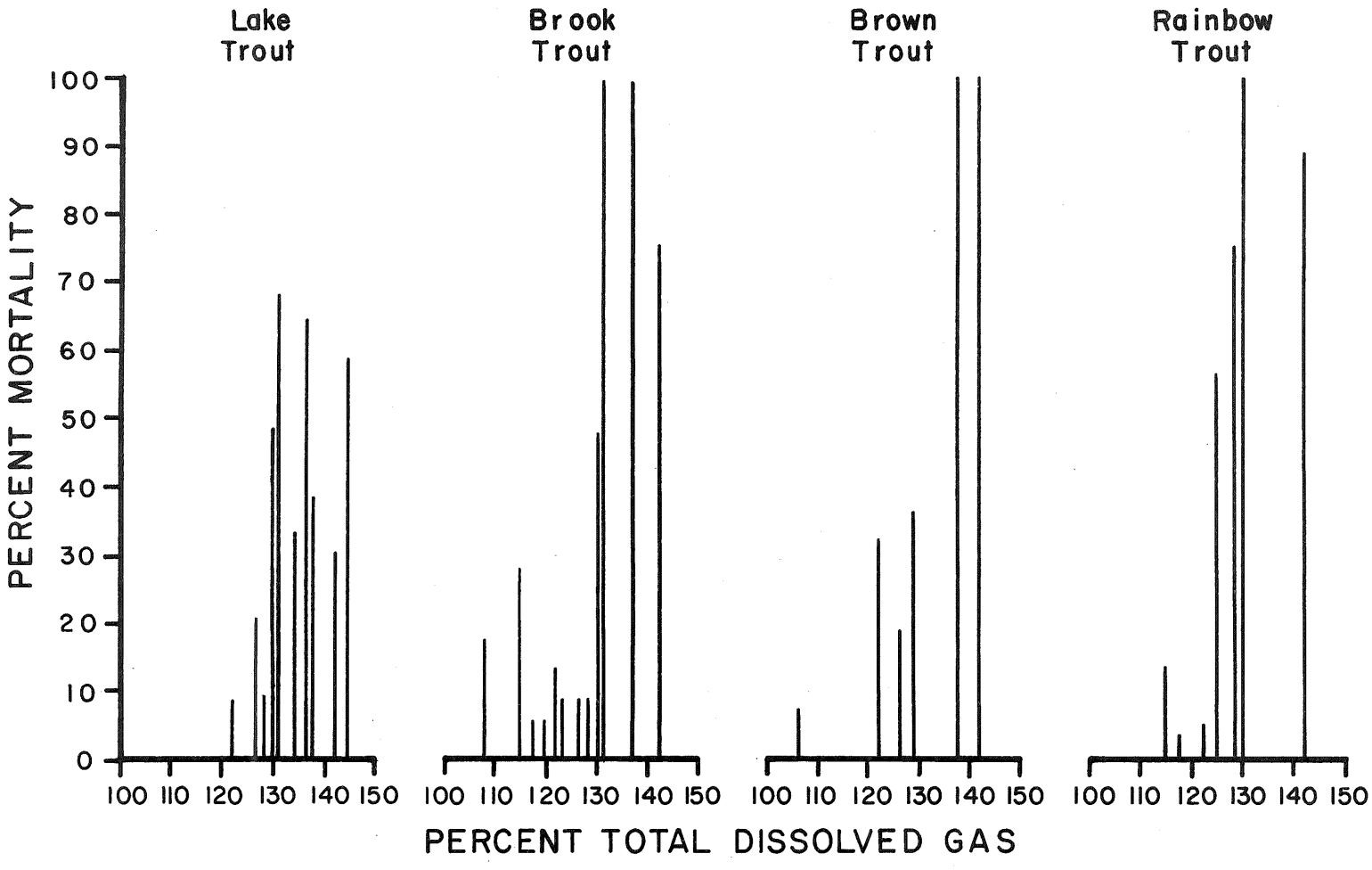

Figure 3. Percent mortality of salmonids after exposure to 7 hours of varying levels of total dissolved gas supersaturation.

Lake Trout

Lake trout were exposed for seven hours to twenty-three levels of total gas supersaturation ranging from 106-144%. The first mortality was recorded at 122% and the greatest mortality (68%) at 131% (Figure 3). Total mortality after seven hours was not attained at any of the levels tested.

Eye damage was common in lake trout exposed to gas supersaturation. Eight lots of 25 fish were observed for 50 days after a seven-hour exposure (Table 1). Frequency of total eye damage increased with gas saturation levels. Hemorrhaging, the most common type of eye damage, was also an initial symptom of gas-bubble disease, and was especially prevalent in fish dying within 24 hours of exposure. Highest incidences of corneal cataract were noted at 120% and 125% total gas saturation.

Growth and food conversion of lake trout yearlings (7.2-8.5 inches) in two water supplies was monitored for 176 days at the Lanesboro State Fish Hatchery. The two raceways were in series; with the water in the lower one being de-gassed 3-4% by spilling between the raceways. Lake trout in this de-gassed water supply grew about 25% faster and converted 40% better than did the fish in the upper, spring-fed raceway.

Table 1.-Eye damage of lots of 25 lake trout observed for 50 days after seven hours of exposure to various levels of gas supersaturation.

% Gas Saturation	Mortality	No. With Popeye	No. With Cataract	No. With Eye Hemmorrhage	Total No. With Eye Damage
106	3	0	4	9	13
107	9	1	9	4	14
115	10	2	4	10	16
120	13	1	10	5	16
125	19	3	11	6	20
125	13	3	12	4	19
141	15	2	6	8	16
146	18	3	4	17	24

Another lot, starting as fingerlings (2.5 inches), was reared in these two raceways for 650 days. During this period there was no difference in growth or conversions of fish in the two water supplies. However, for the first 176 days (the same test period as for yearlings) the growth and conversions were better for fish in the de-gassed raceway; but these differences were not as great as those for yearlings.

Lake trout fingerlings held in the laboratory for 29 days at 113% and 101% total gas saturation grew 18% better and converted 42% better at the lower concentration. Six fish had eye damage at the higher concentration but no damage was noted at the lower concentration.

Brook Trout

Brook trout were exposed for seven hours to seventeen concentrations of total gas supersaturation ranging from 106%-142%. The first mortality was recorded at 106%, but the next mortality was not noted until 115%. Total mortality occurred at 130% and 136%. Incidence of eye damage was not as great as that for lake trout.

Brown Trout

Brown trout were exposed for seven hours to sixteen levels of total gas supersaturation ranging from 106%-142%. The first mortality was noted at 106% but the second was not noted until 122%. Complete mortality was recorded at 135% and 142%. Eye damage of brown trout was uncommon.

Rainbow Trout

Rainbow trout were exposed for seven hours to eighteen levels of total gas supersaturation ranging from 106%-142%. The first mortality was recorded at 115% and total mortality occurred at 130%.

Eye damage was common in rainbow trout exposed to gas supersaturation. This species appeared less susceptible than lake trout and brook trout but more susceptible than brown trout. For example, at 120% gas saturation rainbow trout showed a bubble in the eye while lake trout had a bubble and hemmorrhaging.

Areas on the body of the rainbows where bubbles accumulated also were noted as subsequent points of fin rot infection.

Muskellunge

After seven hours of exposure to 119% and 127% gas saturation, 22 of 22 and 16 of 19 fry, respectively, had a large bubble in the abdominal cavity. No deaths were recorded, but affected fish were unable to swim downward and were stranded on the surface. Fry exposed to 109% and 114% appeared to be unaffected.

White Sucker

Several stages of white sucker fry were subjected to gas supersaturation. No symptoms were noted in sac fry at 119% and 127%, in swim-up fry at 109% or in free-swimming fry at 119% and 127%.

Fathead Minnows

Fathead minnows (1-2 inches) exposed for seven hours to gas saturation concentrations ranging from 126%-129% began to swim listlessly at the surface and develop popeye, and mortality was noted. Fish were not affected at 124%.

Bluegills

Bluegills (2-4 inches) were exposed for seven hours to eleven gas saturation concentrations ranging from 113%-129%. Observed symptoms of affected fish were: hemorrhaging at the choroid fissure of the eye; gas bubbles in fin membranes and reddened fins; swimming with head down, indicating overinflation of the gas bladder and a tendency to rise to the surface, or floating on one side on the surface; and strong opercular movement. Symptoms and mortality were noted at all concentrations (Table 2) and increased with increasing gas saturation concentrations.

Persisting resistance after multiple exposures was indicated for tolerant individuals. Surviving fish from exposure to 113%-120% were subjected to 129% and no symptoms or mortality were noted. These same fish were then exposed to 127%, again with no symptoms or mortality.

Table 2.-Number with symptoms and mortality from lots of 25 bluegills exposed for seven hours to various levels of gas supersaturation

% Gas Saturation	No. with Symptoms	Mortality after 24 hours
113	2	5
113	9	1
113	5	
114	3	6
114	7	15
119	11	11
119	25	20
121	3	12
127	10	9

DISCUSSION

Mortality of the four salmonids generally was first noted at 120%-125% total gas saturation (130%-135% nitrogen saturation). Mortality of salmonids from nitrogen supersaturation has been reported in the range of 120%-140% (Beiningen and Ebel, 1970; Westgard, 1964; Wyatt and Beiningen, 1971).

Lake trout appeared to be more tolerant of gas supersaturation than brook, brown, or rainbow trout. Total mortality of lake trout was not achieved at 144% gas saturation. All brown trout died at 137% and all brook and rainbow trout died at 130%. Posten et. al. (1973) reported greater mortality for rainbow trout than for brown trout at 120% nitrogen saturation.

Variation in tolerance to gas supersaturation was noted among the four warm-water species tested. Bluegills appeared to be the least tolerant with mortality recorded at 113% total gas saturation. Muskellunge fry were affected but not killed at 119% while fathead minnows were not affected or killed until testing at 126%. White sucker fry were most resistant with no effects noted at 127%.

Gases in most teleosts are commonly exchanged mainly across the gill surfaces. Other exchange surfaces may be the swim bladder, alimentary canal and general body surfaces (fins, cornea, pseudobranch). A gas supersaturated in the environment will tend to diffuse into the fluids of the fish through one of these areas, and equilibrate in concentration. This diffusion and equilibration is time dependent and may explain why fish do not die immediately upon exposure to gas supersaturation. Supersaturated gas in the body fluids is unstable and will come out of solution to form bubbles. These bubbles form large gas emboli which may block large blood vessels and lead to death.

Gas bubbles in the circulatory system may impede circulation to the heart or damage adjacent organs. Bubbles were noted in the heart and in the post-caval vein prior to entering the heart. These bubbles have been observed to expand the post-caval vein into the kidney of a lake trout. Pauley and Nakatani (1967) found histopathological changes in the kidney and seven other organs or tissues of chinook salmon fingerlings.

Fish appear to be able to remove accumulations of gas from the circulatory system below a certain level. Above this level, gas must be removed or it will be resorbed into the circulatory system and may accumulate as bubbles. The gas gland and rete mirabile of fish concentrate gas into the gas bladder and also allow resorption of excess gas into the circulatory system for removal by the gills (Lagler et. al., 1962). Trout were seen in the laboratory and in raceways expelling air bubbles through the mouth. This seems to indicate that fish with a pneumatic duct connecting the gas bladder to the esophagus (physostomes such as salmonids, minnows, suckers, pike) would have an additional means of removing excess gas. This may account for the bluegill (physoclistic, without a pneumatic duct) being the least tolerant to gas supersaturation of all species tested. However, Bouck et. al. (1972) found salmonids to be more sensitive than largemouth bass to gas supersaturation.

A possible reason for inter-specific variation among species to lethal levels of gas supersaturation may be the physostomous gas bladder. Increased capillary area on the bladder would allow more dissolved gas to be removed from the bladder, pass into the bladder as free gas, and be expelled through the pneumatic duct. This may explain why bluegills did not die as rapidly as salmonids but floated to the surface at lower concentrations of gas supersaturation. The bluegill and most physoclists have an efficient gas secreting system (Saunders, 1953) whereby gas would be rapidly removed from the blood by the gas gland and rete mirabile and secreted into the gas bladder. Then the limiting factor in survival during exposure to gas supersaturation would be the capacity of the gas bladder.

Lake trout were the most tolerant to mortality from gas supersaturation but showed the highest incidence of eye damage. Brown trout had the least eye damage and brook and rainbow trout were intermediate. After exposure to 120% total gas saturation, lake trout had hemorrhaging and a bubble in the eye; but rainbow trout showed only a bubble. Posten et. al. (1973) found a greater incidence of popeye in experimental brown trout than in rainbow trout; and noted cataract in brook, brown, and rainbow trout reared in water thought to be nitrogen supersaturated. Hemorrhaging and popeye have been reported in salmon and steelhead trout with gas bubble disease (Ebel, 1969; Westgard, 1964).

Hemorrhaging was the first sign of eye damage in lake trout and was followed by corneal cataract. After exposure to 115% gas saturation, lake trout developed eye hemorrhaging; while exposure to 132% resulted in hemorrhaging and cataract. Posten et. al. (1973) found popeye to precede cataract in brown and rainbow trout. Retinal detachment and subsequent hemorrhaging as the result of gas accumulation in vessels of the choroid plexus of the eye was reported by Stroud and Nebeker (1974).

Cataract is any cloudiness of the lens (Steucki et. al., 1968). Allison (1963) stated that the cause of cataract was an inflammation in the eye. Hoffert and Fromm (1965) found that cataract was initiated by an ulceration of the cornea and followed by the lens being pushed through the cornea or being absorbed, resulting in blindness. They also stated that a cause of corneal ulceration may be the differences in osmotic gradients. Such gradients may be present during exposure to gas supersaturation, which could lead to hemorrhaging and cataract.

Eye damage often occurred after exposure to sub-lethal concentrations of total gas saturation. After a month of exposure to 113% total gas saturation, 20% of the lake trout fingerlings showed eye hemorrhaging and 4% had cataract. Posten et. al. (1973) also found that chronic levels of gas supersaturation produced eye damage in brown and rainbow trout.

Exposure to gas supersaturation may lower the fishes' resistance to hatchery diseases. Sites of gas bubble accumulation later became infected with fin rot. Coutant and Genoway (1968) noted fungus on fins of salmon where gas bubbles had been seen. Nebeker and Stroud (1974) attributed death of adult sockeye salmon to diseases which stressed the fish during chronic exposure to 115% gas saturation.

Growth and diet efficiency were reduced in lake trout exposed to sub-lethal levels of gas supersaturation indicating the presence of a stress factor. Posten et. al. (1973) found better growth of brown and rainbow trout at 108% nitrogen saturation than at 120%. Dawley and Ebel (1975) reported that sub-lethal exposures to gas supersaturation significantly affected growth of juvenile chinook salmon and steelhead trout.

Wyatt and Beiningen (1971) reported that salmonids exposed to gas supersaturation do not acquire a physiological tolerance to gas supersaturation. They also indicated that prior exposure to gas supersaturation will decrease tolerance to high gas concentrations. However, our data indicates a persisting resistance in bluegills. Pooled survivors of tests ranging from 113%-120% total gas saturation were exposed to 129% and then 127% on consecutive days with no mortality or symptoms.

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