EFFECTS OF GAS SUPERSATURATION ON FISH IN THE COLUMBIA RIVER [1]

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ABSTRACT

Tests have been conducted at the Prescott Field Facility of the National Marine Fisheries Service (NMFS) to determine effects of dissolved gas supersaturation on the survival of fish indigenous to the Columbia and Snake Rivers.

Bioassay tests have provided information necessary to rank several species of fish by tolerance to gas supersaturation. Increased swim-depth enhances survival; therefore, the depth distribution of fish in the river was examined to accurately estimate fish mortality. A sonic detection array was developed and has been used to determine the swim-depth patterns of migrating juvenile salmonids.

Tests conducted to determine if fish can detect and avoid gas supersaturated conditions indicated species variation in salmonid stocks.

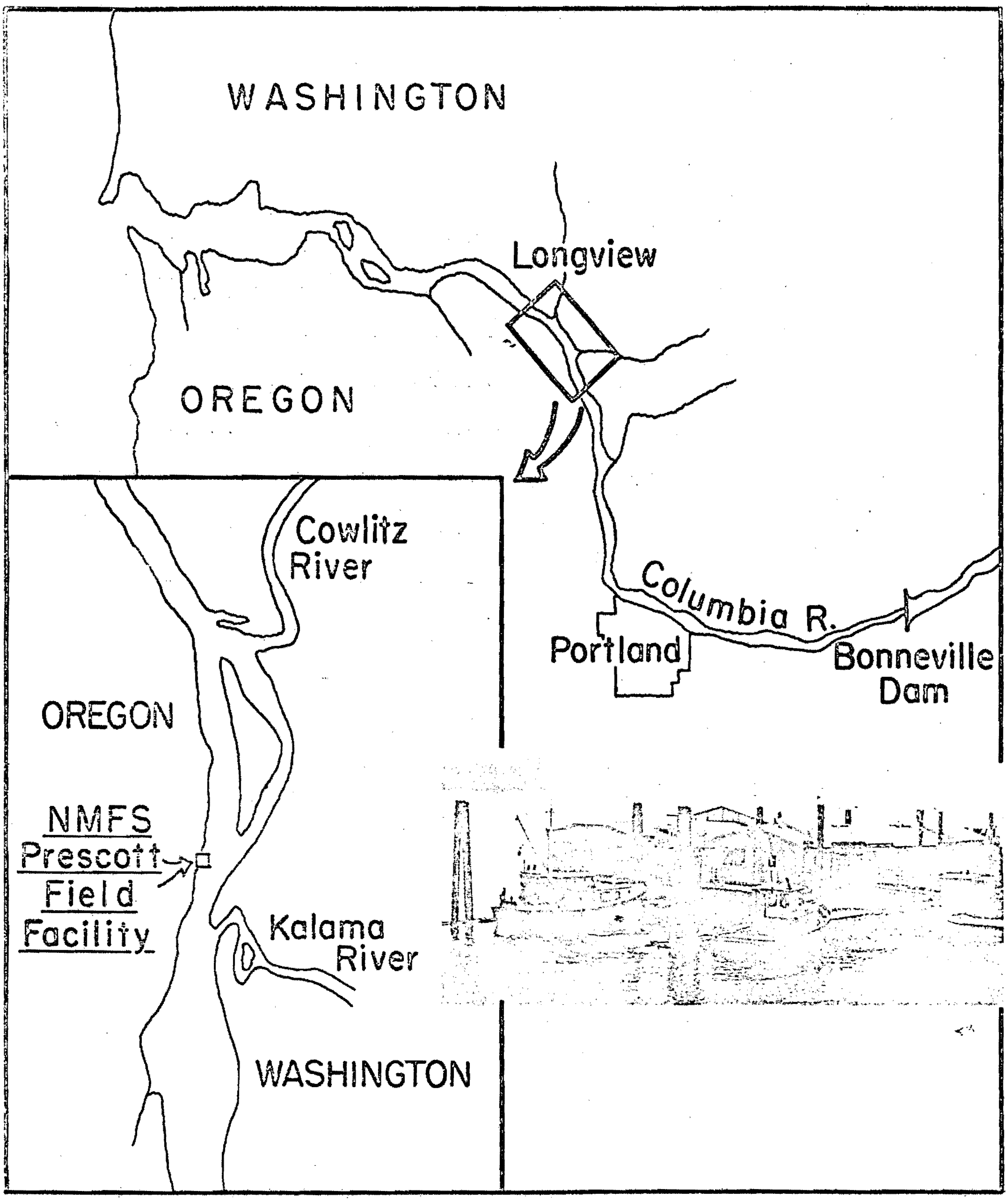
Exposure of selected species of fish to gas supersaturated and equilibrated water on an intermittent time basis indicated all species had better survival than those exposed to constant high saturation conditions.

Various physiological tests were conducted to determine effects of gas supersaturation on: 1) stamina, which was adversely affected, and 2) oxygen consumption, which increased under high gas concentrations, indicating stress.

INTRODUCTION

In 1965, the Bureau of Commercial Fisheries (now National Marine Fisheries Service, NMFS) initiated a monitoring program for dissolved nitrogen gas (N_2) in the Columbia and Snake Rivers to determine seasonal variations in concentrations (Beiningen et al., 1971). Nitrogen gas levels as high as 145% were noted (Beiningen and Ebel, 1970). Ebel (1969 and 1971) published observations of the general effects of nitrogen supersaturation on salmonids in the Columbia Basin. Specific tests, however, have been conducted on the effect of nitrogen saturation on various individual species of juvenile salmonids (Ebel et al., 1971; Snyder and Craddock, 1972; Blahm et al., 1972). In 1972, a base of information was needed to establish regulatory criteria for survival of fish that were being subjected to seasonal variations of dissolved gases.

In 1973 the Corps of Engineers, Bonneville Power Administration, and Bureau of Reclamation provided funds (to the National Marine Fisheries Service) for research on effects of supersaturation of dissolved gases. This report summarizes the results of field studies done at the Prescott Facility (Snyder et al., 1970) (Figure 1) of the Environmental Conservation Division, Northwest Fisheries Center, Seattle, Washington.


WASHINGTON
Longview
OREGON
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Bonneville Dam
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OREGON
NMFS Prescott Field Facility
Kalama River
WASHINGTON

BIOASSAYS

Two types of dissolved gas bioassays were done at the Prescott Facility: (1) a series using deep (2.5 m) and shallow (1 m) tanks supplied with ambient Columbia River water (unaltered except for gas equilibrated controls) and (2) tests in 175 liter tanks (0.35 m water depth) with nitrogen gas levels that were artificially created at 130, 120, and 110% saturation.

Deep and Shallow Tank Studies-Prevailing River Conditions

The objective of these tests was to determine if fish survival increased if the option to sound was provided by use of deep test tanks. Summarized in Table 1 are the: (1) number, size and species of test fish (2) number of days held during test and (3) ranges and average nitrogen levels. Also included in Table 1 is the percent mortality that occurred in the tanks. The N_2 levels as indicated were the naturally prevailing Columbia River levels during the tests. The shallow control tank was supplied with air equilibrated Columbia River water. With the exception of N_2, all parameters remained within safe biological ranges throughout the test period.

Survival was better in the deep tanks (Table 2). This is what one would expect knowing that as hydrostatic pressure increases (with water depth) the percent of nitrogen supersaturation decreases. In these tests crappie and squawfish were the most tolerant while smelt were the least tolerant (scientific names of test fish are listed in Appendix Table 1). This ranking may have been affected by the difference in behavior of test animals; squawfish tended to reside on the bottom of the test tank compared to mid-depth distributions by other species.

Table 1 -- Summary of the numbers of test fish for each species and the percentage of mortality that occurred in the three tanks (2 each 1 m deep and a 2.5 m deep tank) used for bioassays at the Prescott Facility. Included in the table is the number of days the fish were held and the N_2 saturations.

			TEST TANK WATER DEPTH				PERCENT N_2	
Species	Number of Fish	Average Length of Fish mm	(Equil) 1 m	1 m	2.5 m	Days Fish Held	Range During Test	Avg.
			Percent Mortality					
Cutthroat 1/	50	252	10	60	40	59	119 - 136	124
Cutthroat	50	250	8	40	27	49	112 - 130	120
Steelhead	80	191	10	80	6	55	112 - 129	120
Chinook	95	72	0	80	11	55	112 - 129	120
Crappie	50	214	0	0	0	20	117 - 123	120
Squawfish	20	367	0	0	0	35	115 - 124	120
Suckers	58	365	15	33	2	46		116
Smelt	75	181	30	100	40	12	119 - 122	121

1/ Scientific names of fish utilized in tests are listed in Appendix Table 1.

Except for smelt, salmonids were the least tolerant of the species tested. Cutthroat trout were slightly more tolerant than either chinook or steelhead. These general conclusions apply only to the N_2 levels as indicated in Table 1.

Shallow Tanks - Induced Supersaturation

Tests were conducted in 175 liter tanks to provide biological information on the effect of specific and constant levels of dissolved gas on fish survival. Groups of from 5 to 20 fish were held in separate tanks at 130, 120, 110 and 100% nitrogen (N_2) saturation; tests continued for 192 hours during which time mortality was recorded. Water quality parameters remained in exceptable biological ranges with the exception of N_2. The time (hours) to 50% mortality at 130, 120, and 110% N_2 saturation is summarized in table 2 for indicated species and size. Mortality did not occur in the control tanks containing equilibrated (100% saturation) water.

Bass and crappie were the most tolerant of the species tested while smelt were least tolerant. Rainbow trout were the most tolerant of the salmonid species while steelhead were the least tolerant at the 130% level. The 50% mortality level for salmonids excluding rainbow trout, appears to be grouped around 24 hours exposure when tested at 130% N_2 saturation.

DETECTION AND AVOIDANCE

Tests were designed to determine if juvenile salmonids would respond laterally to a choice of supersaturated and equilibrated nitrogen levels. Information of this nature would indicate if fish could detect, and attempt to avoid, areas in the river where gas supersaturation prevailed.

Table 2 -- Time (in hours) to 50% mortality for groups of fish held at 130, 120, 110, and 100% N_2 saturation for 192 hours (species ranked in order of tolerance at the 130% level).

Species	Average Fish Length mm	PERCENT N_2 SATURATION 130	120	110	100
		Hours to 50% Mortality			
Crappie	66	(20)1/ 192.0 (1)2/	*	*	*
Crappie	222	55.0	*	*	*
Largemouth bass	68	220.0 (2)	*	*	*
Largemouth bass	72	102.0	*	*	*
Largemouth bass	72	93.5	*	*	*
Rainbow	63	70.5 (3)	192.0	*	*
Rainbow	77	47.0	141.5	*	*
Rainbow	61	31.0	*	*	*
Chinook	100	64.0 (4)	*	*	*
Chinook	102	24.0	*	*	*
Coho	79	26.0 (5)	59.0	*	*
Coho	82	22.0	118.0	*	*
Cutthroat	99	24.0	119.0	*	*
Whitefish	218	23.0	50.0	*	*
Whitefish	243	23.5 (7)	95.5	*	*
Whitefish	228	21.5	69.5	*	*
Steelhead	131	16.0 (8)	72.0	*	*
Steelhead	124	16.0	N/T 3/	N/T	N/T
Smelt	165	5.5 (9)	30.0	*	*

* = No 50% mortality
1/ 20% mortality in 192.0 hours
2/ Number in parenthesis ranking of tolerance
3/ NT - No Test

Two homogeneous groups of juvenile salmonids were introduced into a test tank providing them a choice of channels carrying either supersaturated water (130% N_2) or gas equilibrated water (100% N_2 saturated). Replicate tests were conducted, by switching the "high" N_2 and "low" N_2 channels. A twenty fish sample of steelhead trout (avg. 137 mm) or chinook salmon (avg. 110 mm) was used for each test.

During the first test with steelhead, 50% died in 42.5 hours; in the replicate test a 50% mortality was reached in 43 hours. Survivors from both tests had external gas bubble disease symptoms.

No mortalities occurred in the two replicates tests (192 hours) with chinook and only 10% showed external N_2 symptoms.

Test results indicate that juvenile steelhead did not avoid the high gas concentration while fall chinook salmon did. Results from other exposure tests show juvenile steelhead to be less tolerant to dissolved nitrogen than chinook. These tests indicate the possibility of species variation in lateral response to nitrogen; however, additional tests should be done to confirm this conclusion.

INTERMITTENT EXPOSURE

As flow conditions change at hydroelectric projects on the Columbia and Snake Rivers the dissolved gas content varies in relation to the volume of water spilled. Information was needed to determine if daily changes in dissolved gas content affects the survival of indigenous fishes. If significant changes in survival were apparent then coordination of water flows in the river could be accomplished to either increase or decrease fluctuation of spill volume for the desired effect i.e., protection of aquatic resources.

Tests were conducted to assess the effect of intermittently exposing fish to high (130, 120, and 110%) and then equilibrated levels (100%) of nitrogen gas saturation.

A diagramatic representation of N_2 levels and the time base used for the tests is shown (Figure 2). The alternating cycle was continued for 192 hours (8 days).

The results of the intermittent exposure tests are summarized in table 3; included is the time (in hours) to 50% mortality when test fish were exposed to 130% or 120% N_2 for 24, 16, and 8 hours. Tests at 110% are not included as the mortality level was not generally reached; however, some mortality did occur during tests with bass and whitefish. At the 130% level steelhead and whitefish, exposed on the intermittent time base, did not receive significant benefits when returned to equilibrated water.

At the levels tested, and the time frame used, intermittent exposure to supersaturated and equilibrated water enhanced fish survival over that recorded for a constant (24 hour) exposure to the supersaturated condition. However, it is doubtful that a time frame of intermittent spill at lower Snake River Dams could be created that would alter the gas saturation levels to the extent that would provide a dramatic increase in fish survival. The possibility of effective intermittent spilling might exist at other dams, with a larger storage to power output ratios, such as Libby or Brownlee.

VERTICAL DISTRIBUTION OF FISH BY USING DEPTH SOUNDING GEAR

In 1972 a Benmar [1/] depth sounder was modified to determine the depth distribution of juvenile salmonids in a 3 m laboratory test tank. A printer/counter system in conjunction with electronic gates provided a readout of number of fish in each 0.6 m interval of water in the 2.5 m tank.

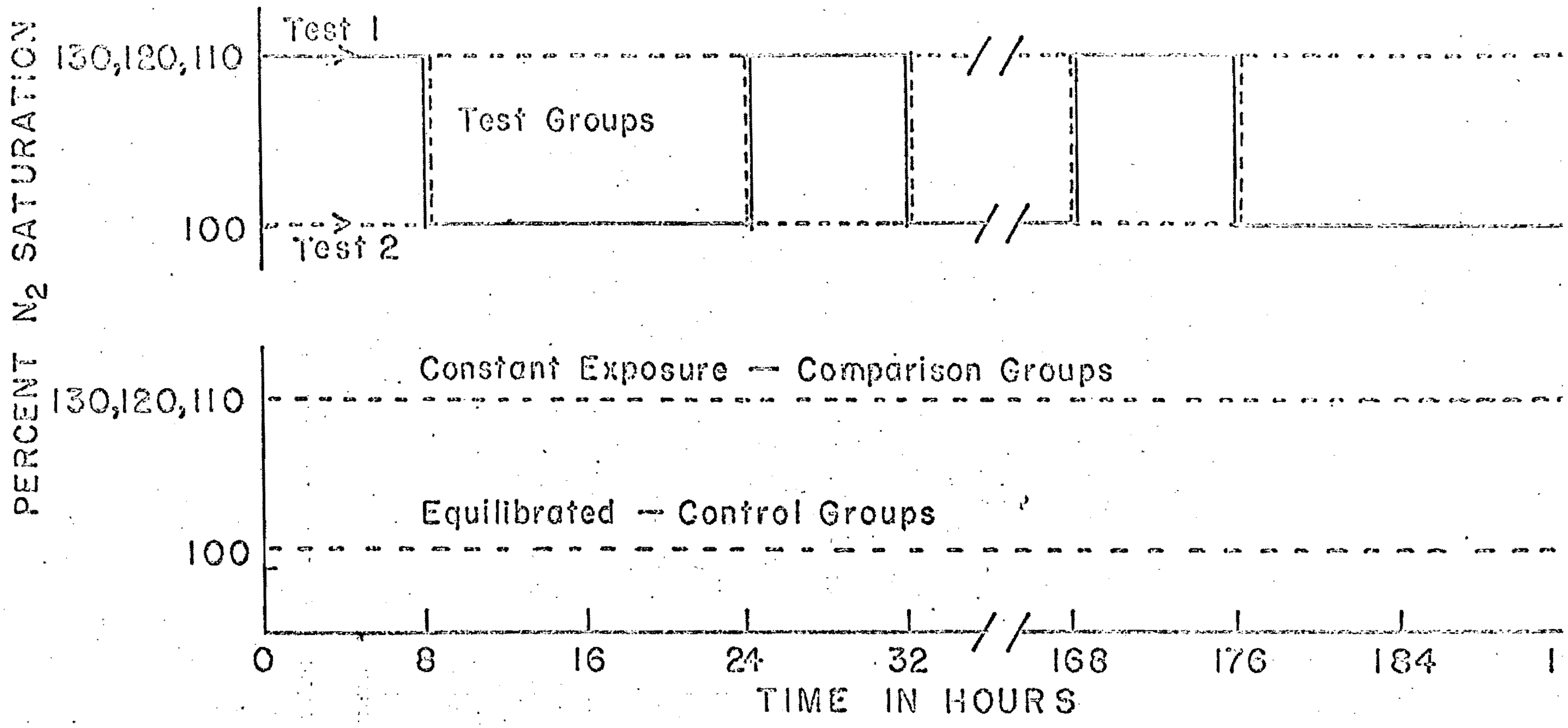

Figure 2.--Nitrogen percent saturation and time base used for intermittent exposure tests. Test groups were intermittently exposed to either 130, 120 or 110% N_2 for either 8 or 16 hrs then returned to 100% N_2 (equilibrated) for the remainder of each 24 hr period. Comparison groups were exposed continually to the supersaturated condition until 50% mortality occurred or until test termination at 192 hrs. Control groups were held throughout the test period in 100% N_2 water.

Table 3 — Time in hours to 50% mortality for juvenile salmonids and non-salmonids subjected to 130 and 120% N_2 saturation for either 24, 16, or 8 hours of each 24 hour cycle during 192 hour intermittent exposure test. The fish were alternately exposed to the super-saturated condition and equilibrated water.

		PERCENT N_2 SATURATION					
		130			120		
		Number of hours during each 24 hour cycle fish were subjected to supersaturation					
Test Species	Average length of fish mm	24	16	8	24	16	8
		Time in hours to 50% mortality					
White crappie	66	*	*	*	*	*	*
Largemouth bass	72	93.5	*	*	*	*	*
Largemouth bass	72	102.0	*	*	*	*	*
Chinook	100	64.0	*	*	*	*	*
Chinook	102	24.0	120.0	*	*	*	*
Rainbow trout	77	47.0	69.5	*	141.5	*	*
Rainbow trout	61	31.0	*	*	*	*	*
Coho	79	26.0	46.0	102.0	59.0	*	*
Coho	82	22.0	*	*	*	94.0	*
Cutthroat trout	99	24.0	72.0	103.0	*	*	*
Whitefish	243	23.5	23.5	*	95.5	*	*
Whitefish	228	21.5	21.5	99.0	69.5	145.5	181.5
Steelhead	124	16.0	16.0	*	72.0	*	*

* = No 50% mortality

In the test tank, with the captive fish, two transducers were used, one at the surface and one on the bottom. After examining tapes of several 24 hour tests we determined that the fish were generally below the midline, (1.25 m water depth) this would generally enhance their survival from that in a 1 m deep tank.

The next logical step was to test this equipment in the river. The two transducer arrangement was modified to a 10 transducer array where all transducers were positioned (Figure 3) on the bottom of the river (array has now been modified to a 20 transducer unit). This configuration has been used at two locations near Prescott for a total of 75 hours during day and night. Figure 4 summarizes the results; of 776 fish detected, approximately 72% were located between .9 and 2.1 m (3 and 7 feet). More fish were detected during darkness than daylight. Although species could not be differentiated by the sounder a minimum seine effort (2 sets) at the beaches netted 37 juvenile chinook, 21 crappie, 17 perch, 16 stickleback, 9 flounder, 2 peamouth chum and a whitefish. This indicates that the "sounder" results can be approximately quantified for species composition with a minimum beach seining effort. We feel this method of determining vertical fish distribution will prove fruitful (studies are continuing at Prescott during 1976) and eliminate some problems associated with gill netting.

PHYSIOLOGICAL EFFECTS

Fish Stamina

Fifty juvenile chinook (avg. 103 mm) were timed swimming against a water velocity of 45.7 cm/sec (1.5 fps) in gas supersaturated (128 to

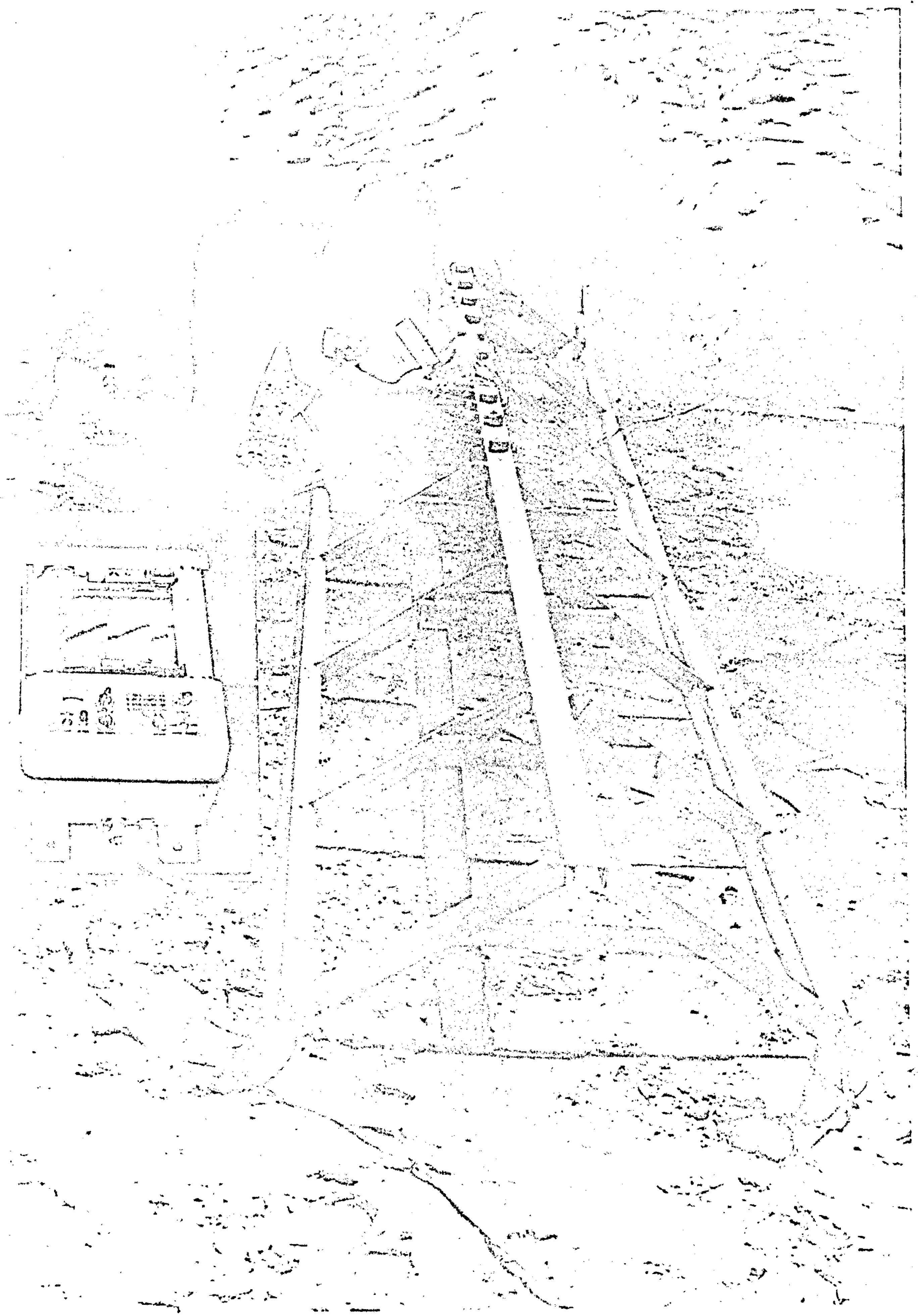

Figure 6 -- Ten transducer sonic array and recorder.

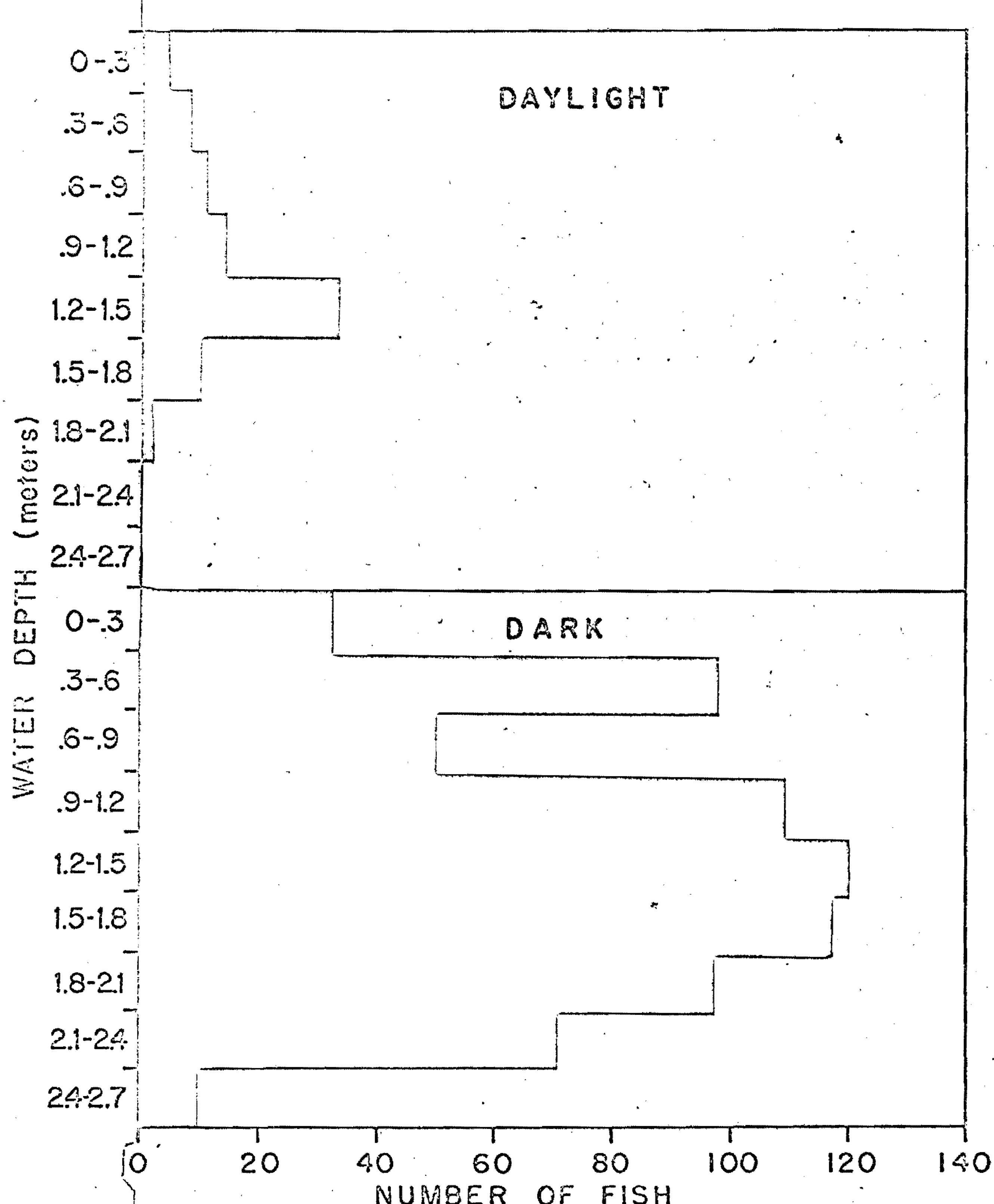
DAYLIGHT
DARK
WATER DEPTH (meters)
0-.3
.3-.6
.6-.9
.9-1.2
1.2-1.5
1.5-1.8
1.8-2.1
2.1-2.4
2.4-2.7
0 20 40 60 80 100 120 140
NUMBER OF FISH

Figure 4 -- Numbers of fish detected (at .3 m intervals) by sonic gear during 75 hours of operation at Columbia River beaches near Prescott, Oregon, 1974.

134% N_2) and air equilibrated (100% N_2) water. The tests were done in a large scate environmental respirometer (Figure 5).

Average swimming time for fish held and tested in supersaturated water was less than that recorded for the control (equilibrated N_2) group. An average swimming time of 17 minutes was measured at supersaturated N_2 and 25 minutes at equilibrated N_2. The results indicate that fish stamina is detrimentally affected by gas supersaturation. The implications are that fish did not operate efficiently in an environment which was supersaturated with atmospheric gases, consequently, the ability of fish to feed, reproduce, and escape preditors would be adversely affected.

Oxygen Consumption

Oxygen consumption of fish is used by many investigators as an index of stress. We used this parameter to indicate the indirect (sublethal) effects of nitrogen supersaturation on juvenile salmonids.

A flow through respirometer (Figure 6) was attached to constant head reserviors which contained air equilibrated and gas supersaturated Columbia River water; the chambers were maintained in a darkened cover and manipulation of supersaturated water was done by remote valving so as to eliminate disturbing the fish during the test.

Three species of juvenile salmonids were tested: (1) coho salmon (2) chinook salmon and (3) cutthroat trout. A brief summary of one test for each species follows:

1. Oxygen consumption of eight coho salmon (avg. 12.5 g and 97 mm) in equilibrated water (103% N_2) averaged 0.121 cc of oxygen per gram of fish per hour (O_2/g/hr) and varied very little over a 98 hour exposure. When this same group of fish were subjected to 123% N_2 saturated water

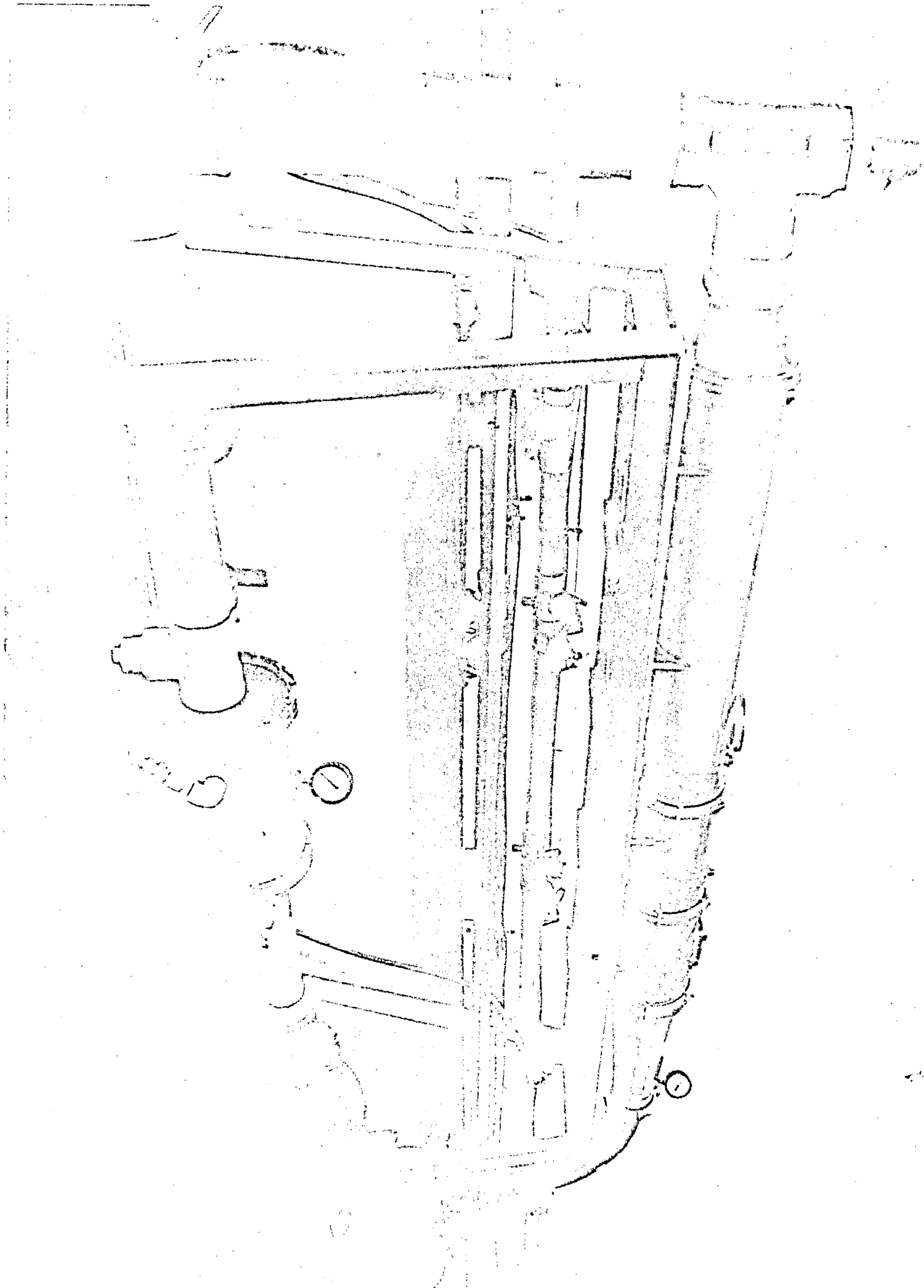

Figure 5 -- Controlled environmental chamber used for fish stamina tests at the Prescott Facility.

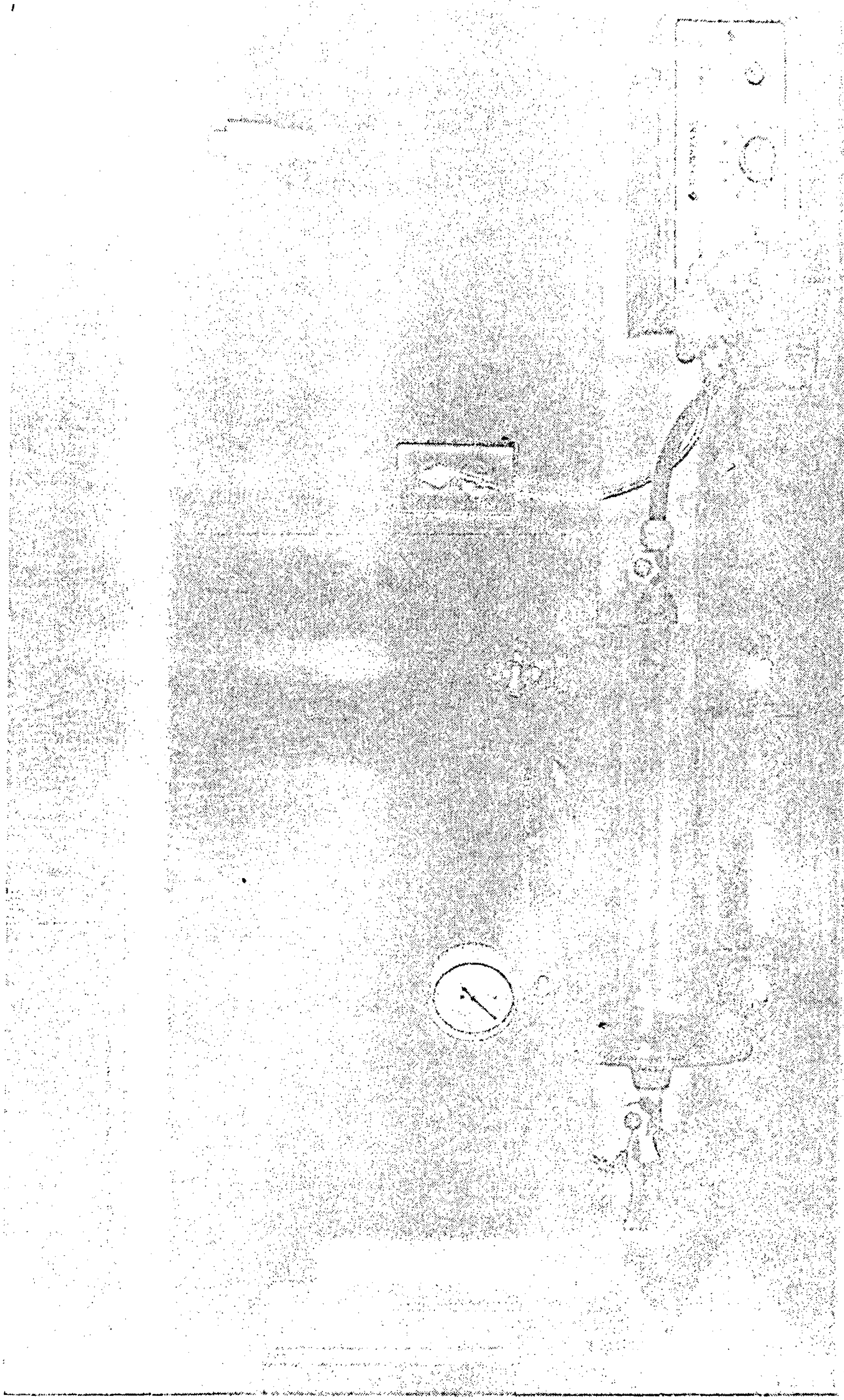

Figure 6 -- Flow through respirometer used for oxygen consumption tests at the Prescott Facility.

the oxygen consumption increased and averaged 0.181 cc/g/hr. over the next 67 hours. At the end of this period O_2 consumption decreased to 0.120 cc/g/hr. and one fish died; the remaining seven had external gas bubble disease signs.

2. Two groups of 10 each, juvenile chinook (avg. 56 g and 79 mm) were tested simultaneously; one in equilibrated water (control group), the other in N_2 supersaturated water. Oxygen consumption of the control group changed little and averaged 0.181 cc/g/hr. during 230 hours of exposure; no mortality occurred. Fifty percent mortality occurred within 50 hours in the test group which was held in supersaturated water (127% N_2). Dead fish were removed and consumption calculations were adjusted accordingly. Consumption reached a high of 0.276 cc/g/hr.

3. Following is a brief table showing time, O_2 consumption and percent N_2 saturation for a group of 10 juvenile cutthroat trout (avg. 12.5 g and 97 mm) tested in a manner similar to that used during the tests with coho:

	O_2 Consumption	N_2 Saturation
Time	cc/gram/hour	Percent
0900	0.149	109
1300	0.142	108
1315 Initiated supersaturation with nitrogen gas		
1400	0.310	133
1500	0.112	149
1600	0.076	152
1900 (Mortality occurred)	0.064	150

In all tests O_2 consumption increased subsequent to supersaturated water being introduced into the chambers; then declined until death occurred. The dead fish exhibited suffication symptoms and blood vessels supplying the gills were inundated with gas bubbles. All survivors from test groups exhibited external symptoms, gas bubble disease was not evident in the control fish.

The primary cause of decreased performance and oxygen consumption is probably an inability to efficiently utilize the available oxygen because of gas bubbles obstructing blood flow within the circulatory system suppling the gills.

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