Effects of 1985–86 Levels of Dissolved Gas on Salmonids in the Columbia River

by

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November 1986

COASTAL ZONE AND ESTUARINE STUDIES

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INTRODUCTION

Gas bubble disease (GBD) in freshwater fishes, resulting from supersaturation of dissolved atmospheric gases in water, has been studied by investigators since the early 1900s (Marsh and Gorham 1905; Rucker and Tuttle 1948; Harvey and Cooper 1962; Shirahata 1966). In the Columbia and Snake Rivers, GBD became evident in the 1960s and was attributed to supersaturation of dissolved gases caused by high volumes of water flowing over spillways at dams (Ebel 1969; Beiningen and Ebel 1970; Ebel 1971; Meekin and Allen 1974). Gas levels over 140% of saturation were not uncommon; from literature it was apparent that 110% was potentially lethal to fish. The problem was intensified for salmonids by an increased migration time, resulting from impoundments created by several new dams on the river.

From 1966 to 1975, estimates of mortality ranged from 40 to 95% for juvenile salmonids migrating from the Snake River; a major proportion of that mortality during high flow years was attributed to GBD (Ebel et al. 1975). During that period, research defined tolerance characteristics of juvenile and adult salmonids to supersaturation and documented dissolved gas concentrations throughout the river during high water flow and spill at dams (Parametrix, Inc. 1975; Ebel et al. 1975; Boyer 1974).

In the early 1970s, extensive efforts were made to reduce spill and to decrease the levels of supersaturation created by spill (Smith 1974). Several actions significantly decreased levels and duration of supersaturation: increased water storage in the upper reaches of the river basin, increased electrical generation at dams on the lower Snake and Columbia Rivers, and installation of flow deflectors on the spillways of several dams. Supersaturation greater than 130% became infrequent instead of common, and levels exceeding 120% [shown by Weitkamp (1976) to be the critical point in causing mortality from GBD in salmon held in situ at Rock Island Dam] were observed less often and in smaller sections of the river basin. As a result of these actions, little evidence of gas bubble disease in salmonids was observed in the late 1970s.

In the 1980s, a program of increased spill at dams was implemented to improve passage of juvenile salmonids. This created diurnal fluctuations of supersaturation within the river system. The U.S. Army Corps of Engineers (COE) and the National Marine Fisheries Service (NMFS) began to reevaluate the effects of current dissolved gas levels on salmon in the Columbia River system, including fluctuating supersaturation caused by designated spill for fish. In 1985, a field bioassay and monitoring program was established to evaluate the impacts of intermittent high supersaturation on both juvenile and adult salmonids. The reservoir of The Dalles Dam [River Kilometer (RKm) 308] was selected as the primary evaluation site because daily spill was expected at John Day Dam (RKm 347). In the 1970s, spill at John Day Dam created the highest dissolved gas levels in the river system, and in the 1980s, high dissolved gas levels resulting from intermittent spill were observed in the forebay of The Dalles Dam.

OBJECTIVES

The objectives of the bioassay and monitoring program were:

1. To obtain daily dissolved gas concentrations in the forebays of John Day and The Dalles Dams.

2. To observe and record signs of GBD in juvenile and adult salmonids sampled at various sites on the river.

3. To determine the migration rate of marked fish passing through The Dalles Dam reservoir.

4. To conduct holding studies with juvenile spring and fall chinook salmon, of hatchery and river-run stock, in The Dalles Dam forebay and examine depth distribution in relation to level of supersaturation.

5. To obtain depth distribution information for juvenile salmonids in the forebay of The Dalles and John Day Dams using hydroacoustics.

6. To assess the probable effects of dissolved gas supersaturation on salmonid migrants and compare the results with information obtained in the 1960s and 1970s.

METHODS

In 1985, the site of most field work was The Dalles Dam and its forebay to a few km upstream (Fig. 1). In 1986, biological data were collected at McNary, John Day, and Bonneville Dams.

Dissolved Gas Measurements

Dissolved gas concentrations were measured in the forebays of McNary, John Day, and The Dalles Dams and at Warrendale, Oregon, (downstream from Bonneville Dam) using continuous monitoring instruments operated by the North Pacific Division of the COE (U.S. Army Corps of Engineers 1985). Generally, measurements were recorded at 3-h intervals, which we believe were adequate for evaluating dissolved gas fluctuations in relation to river flow patterns.

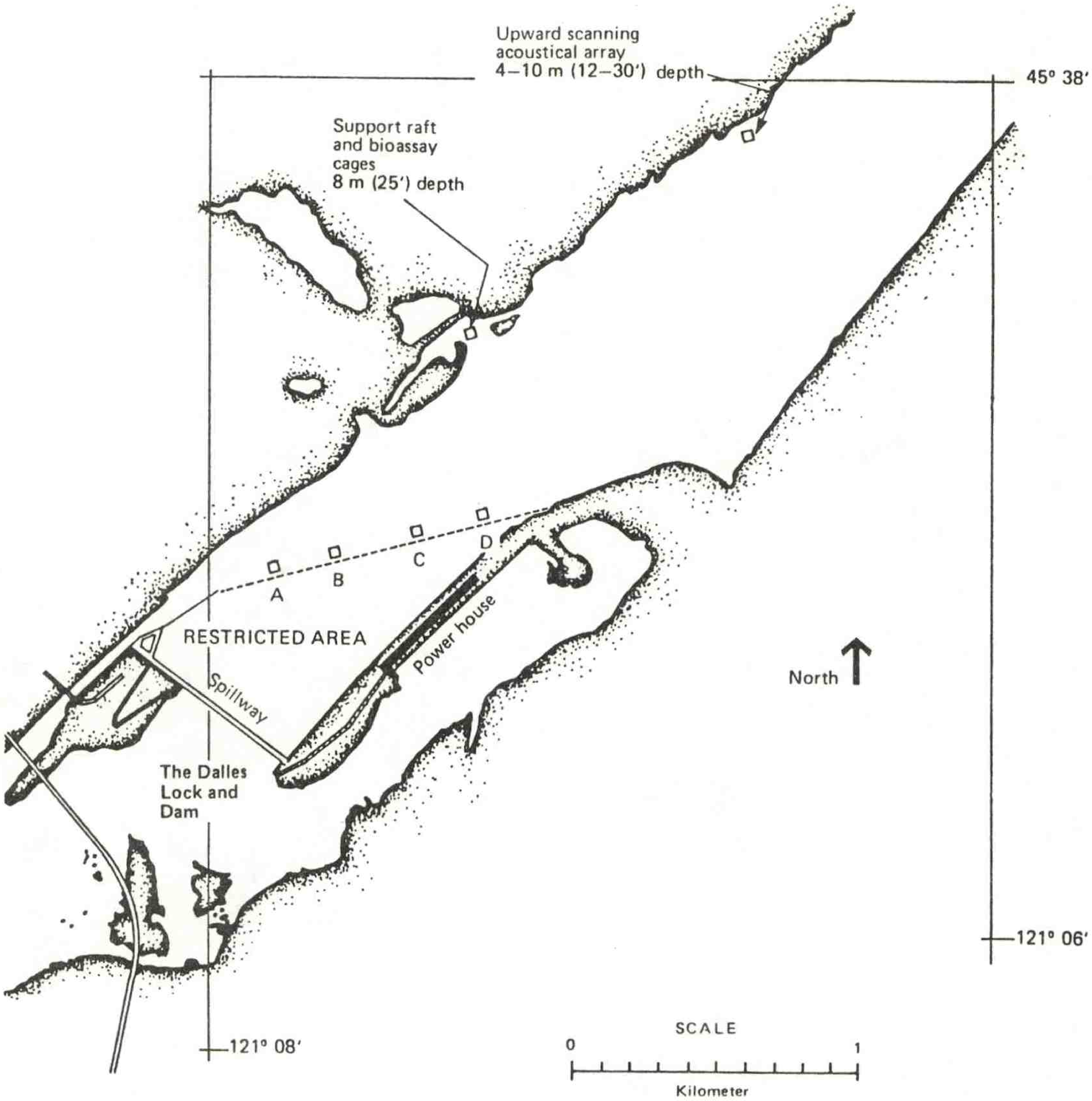

Figure 1.--Location of support raft for bioassay cages, upward scanning acoustical array, and restricted area of The Dalles Dam.

Gas Bubble Disease Observations

From April to June 1985, when gas levels might have caused GBD, NMFS personnel examined juvenile migrants for signs of GBD at John Day, The Dalles, and Bonneville Dams. Fish sampled several days per week for other research projects were also examined for macroscopic cutaneous and subcutaneous gas-filled blisters on the fins and body surfaces. Recoveries of marked fish were also recorded to provide estimates of exposure time to supersaturation during migration through the reservoirs of The Dalles and Bonneville Dams.

Plans for evaluation of GBD in 1986 were cancelled in April 1986 because of a below-average snowpack and little or no spill expected at John Day Dam or any dams other than Bonneville Dam. However, we took advantage of the unexpected high flow period in late May and early June to obtain data on GBD of yearling and subyearling migrants at lower Columbia River dams. Begining 1 June, daily examination for GBD was made by NMFS and Fish Passage Center personnel on 100 or more juvenile salmonids of each species at McNary, John Day, and Bonneville Dams. Adult migrants were examined at the trap in the north-shore fishway at McNary Dam.

Live Cage Studies

To observe the effects of ambient supersaturation on yearling and subyearling chinook salmon of both river-run and hatchery stocks, groups were held in cages 1.5 km upstream from The Dalles Dam. A floating platform was anchored in 8 m of water at the mouth of a slough on the north side of the river. Attached to the platform were six cages 0.6 x 0.6 x 1.0 m deep; two were placed at each of three depths: 0-1, 1-2, and 3-4 m. Two additional cages 0.6 x 0.6 x 6.1 m deep were used to allow unrestricted vertical movement of test fish (Fig. 2).

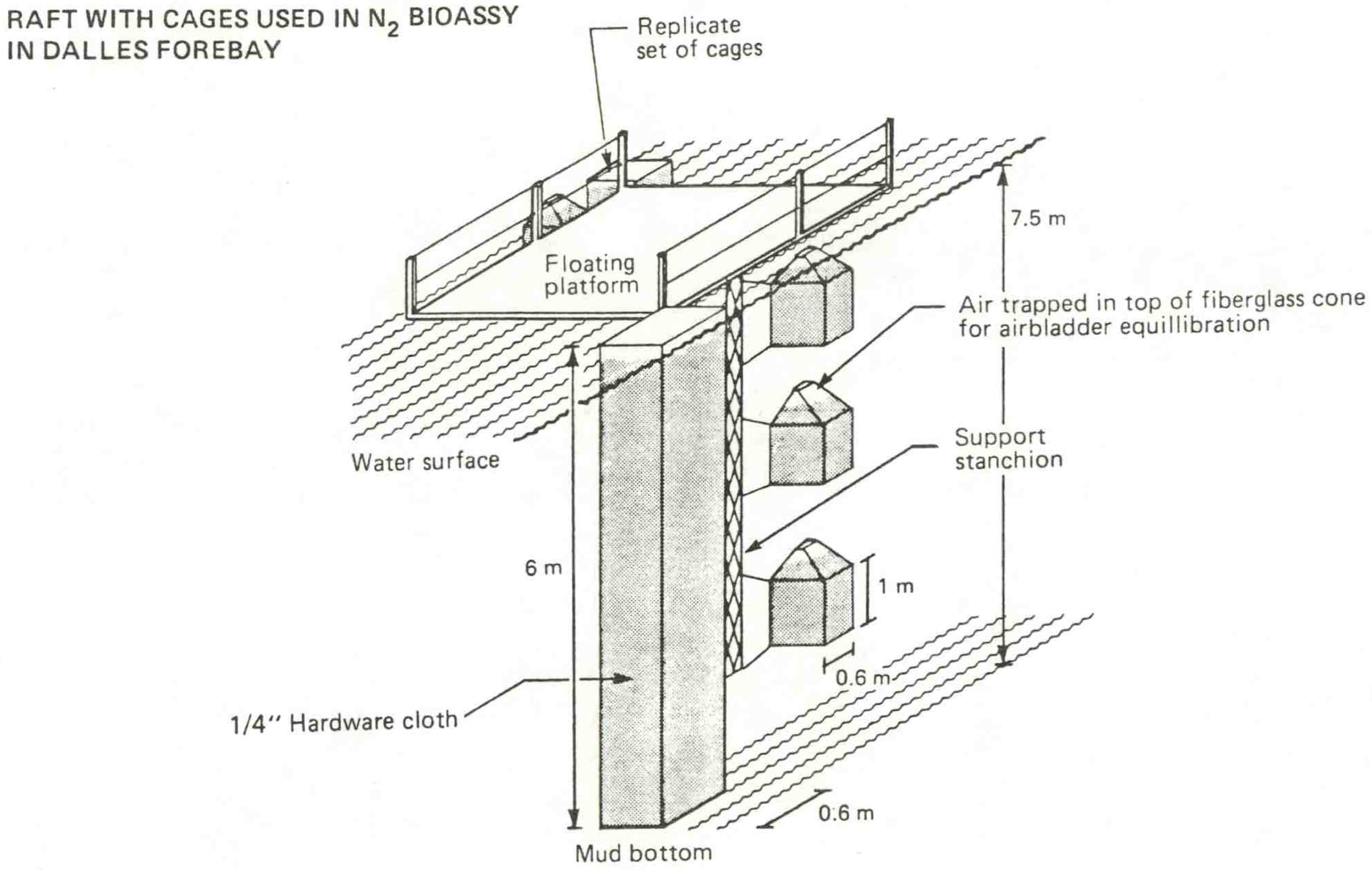

Figure 2.--Support raft with cages used for holding test in The Dalles Dam reservoir. Juvenile spring and fall chinook salmon were held at particular depths to evaluate the effects of spill at John Day Dam.

Holding tests were initiated when dissolved gas concentrations were expected to exceed 120% of saturation. Four- or five-day tests with yearling chinook salmon were begun on 13, 20, and 28 May, giving three replicate tests. Three- or four-day tests with subyearling chinook salmon were begun on 8 and 22 July and 12 August, also giving three replicate tests. Groups of 50 fish were placed in each cage. One set of four cages, positioned at 0-1, 1-2, 3-4, and 0-6.1 m, held river-run fish taken from gatewells at The Dalles Dam; the other set, positioned at the same depth intervals, held hatchery fish of the same age. Hatchery-reared yearling spring chinook salmon were obtained from Eagle Creek National Fish Hatchery (U.S. Fish and Wildlife Service), and subyearling fall chinook salmon were obtained from Washougal Salmon Hatchery (Washington Department of Fisheries). Fork lengths of both river-run and hatchery fish are listed in Table 1.

Fish in cages were observed daily by SCUBA divers at about 1300 h. Dead fish were collected and examined for signs of GBD. Underwater observations for signs of GBD in fish were attempted, but visibility was too poor. The vertical distributions of fish in the 6.1-m cages were recorded. To minimize fish following the divers during assessment of vertical distribution, divers simultaneously approached each cage from the bottom and top and ascended or descended with limited breathing. To enhance future holding tests, an underwater video monitoring system was fabricated which allows diel observations of vertical distribution in the volitional cages and eliminates the necessity for observations by SCUBA divers.

Table 1.-- Fork lengths of yearling and subyearling chinook salmon used in holding tests at The Dalles Dam forebay, 1985.

Test dates	Hatchery fish forklength (mm)		River-run fish forklength (mm)	
	Range	Mean	Range	Mean
		Yearling chinook salmon		
5/13-18	85-235	152	105-205	140
5/20-25	80-230	152	85-195	142
5/28-6/1	112-232	157	80-177	142
		Subyearling chinook salmon		
7/8-12	55-95	80	78-133	103
7/22-26	60-100	87	73-137	108
8/12-15	58-103	93	-[a]	-[a]

[a] No data

Hydroacoustic Depth Evaluation

Hydroacoustic assessments of the vertical distribution of fishes entering turbine intakes and passing over spillways at The Dalles Dam were made by BioSonics Inc.,[1/] under contract to Bonneville Power Administration (Steig and Johnson 1986). A sophisticated network of transducers and data compilation devices were used to examine seven sites at the powerhouse and nine sites at the spillway. Counts were adjusted to screen out electronic interference and to correct for variation of beam width at the target range.

Monitoring of vertical distribution was also attempted by NMFS personnel at the buoy line of the restricted area in front of the dam and at a site 2 km upstream near the shoreline (Fig. 1). The echo sounder used in front of the dam was a Ross Fineline 200-A transmitting at 198 kHz through a sequencing series of four transducers (22°). The transducers were attached to 4-m outriggers on both sides of a boat (Fig. 3). Water depths ranged from 5 to 26 m. The echo sounder used at a fixed position near shore was a Benmar DR-680 transmitting at 400 kHz through a sequencing series of 20 transducers (20°). These transducers scanned upward from the bottom in water depths ranging from 4 to 10 m (Fig. 4) (Marshall 1976). Relative percentages of targets within particular depth ranges were adjusted for cone area at the distance of observation.

[1/] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

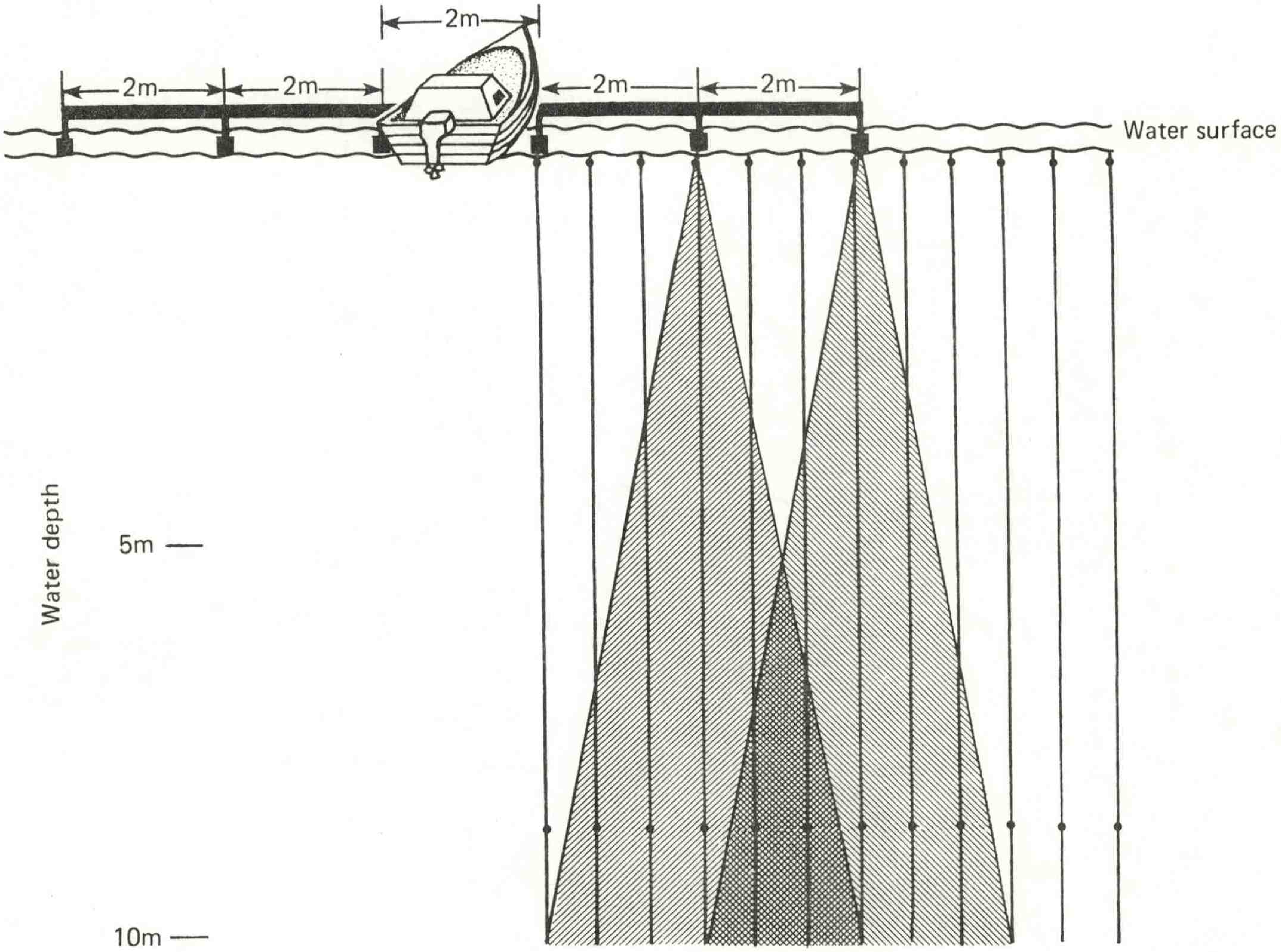

Figure 3.--The echo-sounding scheme 50-100 m in front of the powerhouse and spillway at The Dalles Dam, 1985; Ross fine-line 200-A (198 kHz) and four 22°-trandducers (sequenced).

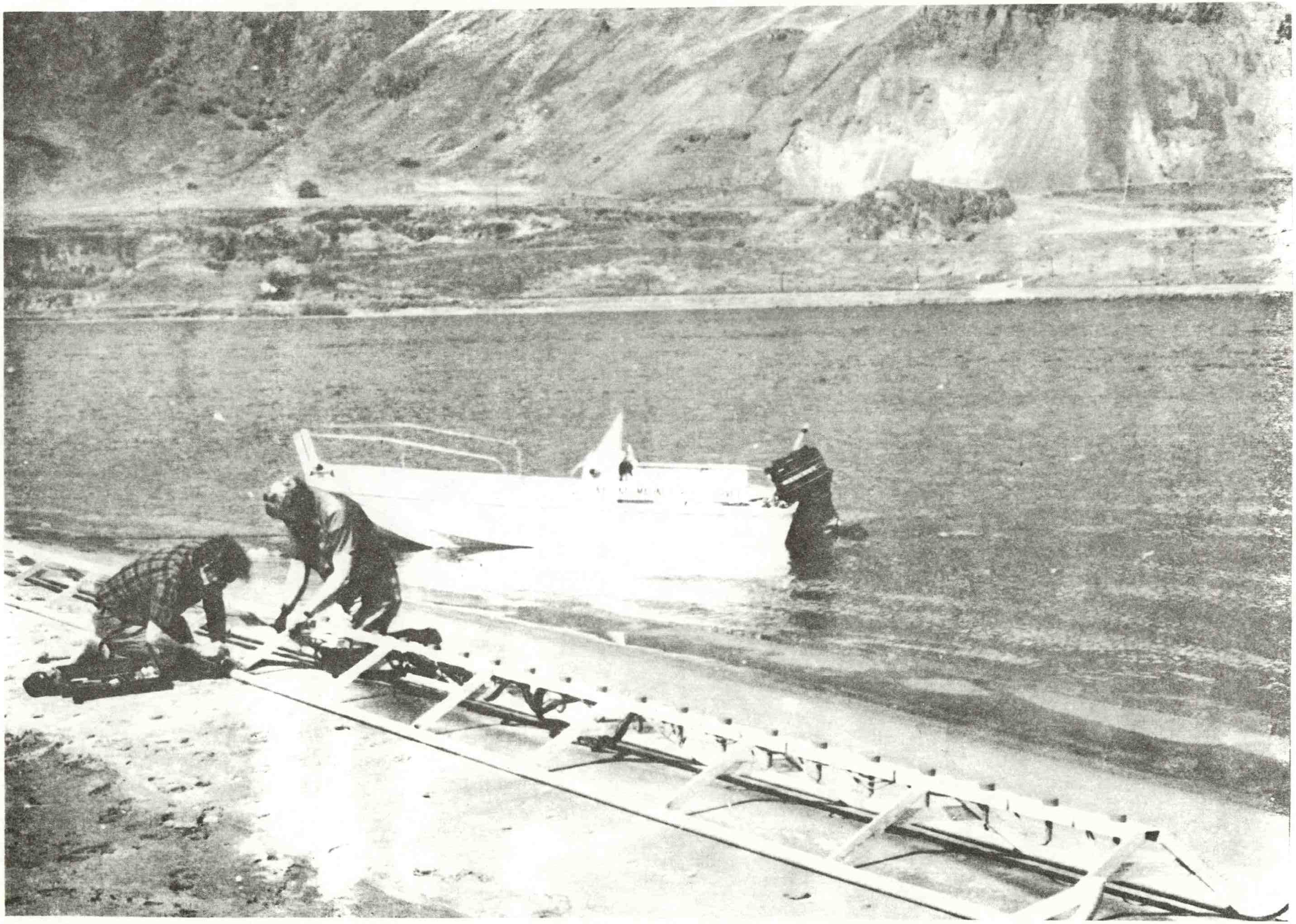

Figure 4.--Twenty-transducer sonic array used near shore 2 km upstream from The Dalles Dam, 1985; Benmar DR-680 with sequencing transducers (from Marshall 1976).

RESULTS AND DISCUSSION

1985

Dissolved Gas Levels

Predicted high flows did not occur in mid- to late-May, nor in other periods during the 1985 migration; as a consequence, dissolved gas concentrations in The Dalles reservoir seldom exceeded 120%. Because of the extensive setup efforts, we continued to evaluate the prevailing low supersaturation conditions. These data were collected for comparison with past laboratory and field data and with future field tests conducted at higher levels of supersaturation. Average daily flows during the evaluation were low for this time, ranging from 292 thousand cubic feet per second (kcfs)[2/] on 6 May to 64 kcfs on 28 July. Highest supersaturation values were observed in early May when daily spill lasted about 8 h and passed from 40 to 60% of the instantaneous flow through John Day Dam. In The Dalles reservoir, diurnal saturation levels near 120% were observed for about 8 h, levels below 110% of saturation for about 8 h, and intermediate levels during the interim (Fig. 5).

A comparison of spill rates at John Day Dam versus dissolved gas levels at The Dalles Dam (26 April to 17 May; river flows 170-292 kcfs) indicates that water passage time through The Dalles reservoir was 16 to 20 h (Fig. 5). Spilled water appeared to move through the reservoir as distinct masses. The durations that high and low supersaturated water passed through The Dalles Dam corresponded to the duration of high and low volumes of water spilled at John Day Dam hours earlier (Fig. 5).

[2/] The English units kcfs are used in this report in place of metric units because of common local usage (1 m^3 = 35.3 ft^3).

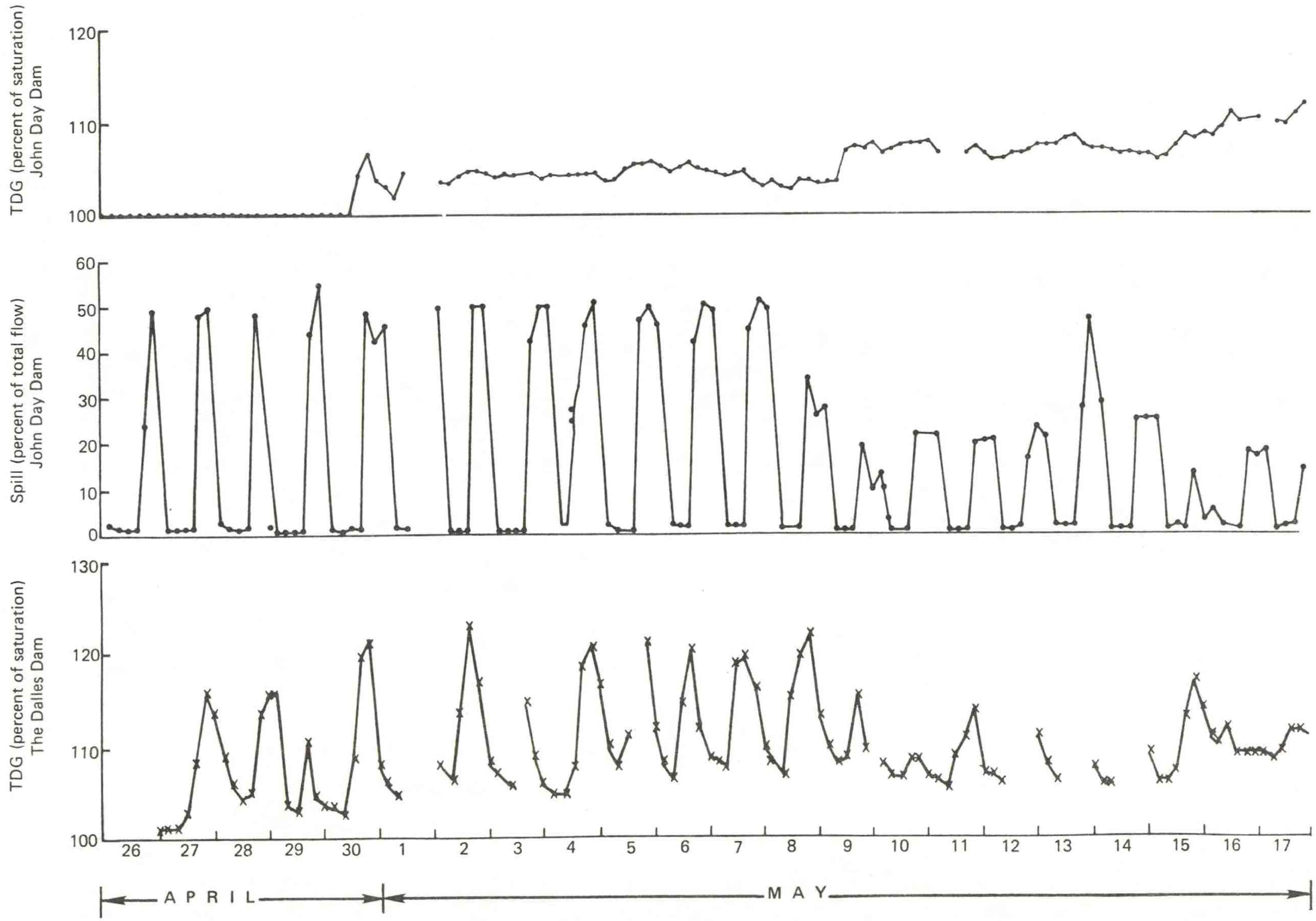

Figure 5.--Total dissolved gas (TDG) concentrations at John Day and The Dalles Dams, with spill flows in 3-h intervals, 26 April-17 May 1985.

Gas Bubble Disease in Migrants

During the period of highest supersaturation, the first week in May, signs of GBD were not observed in fish examined at The Dalles or Bonneville Dams. Dissolved gas levels were, however, only slightly greater than 120% of saturation for a few hours a day. Had the juvenile salmonids encountered 120% saturation for > 12 h diurnally, GBD signs would probably have been observed (Dawley and Ebel 1975). From mark recovery data we estimated that migration time through The Dalles reservoir was from 1 to 2 days for yearling chinook salmon. Migrants intermittently encountered supersaturation for several more days, because only slight equilibration of dissolved gas (change of gas concentration toward normal saturation -- 100%) occurs in the river from The Dalles Dam to the estuary (from interpretation of dissolved gas data, 1966-1985). Some fish may have developed GBD downstream from Bonneville Dam, but the effects were probably not lethal even for fish swimming at the surface. Fish swimming at depth are provided compensation from supersaturation conditions by hydrostatic pressure. Each meter of depth provides about a 10% decrease in percent of saturation, therefore, fish swimming at 1 m encountered about only 110% of saturation.

Live Cage Studies

Gas Bubble Disease.--Consistent with observations of river-run juveniles at the dams, GBD signs were not observed in caged fish held for 5 days. Daily saturation levels during the first test of yearling chinook salmon were highest (111-118%) for about 8 h and substantially less for the other 16 h (Table 2). Signs of GBD on live fish in the cages could have been present for a day or two, however, visibility for SCUBA divers was too poor for that observation. Signs were not apparent at the end of the test when fish were

Table 2.-- Mortality, dissolved gas concentrations, and water temperatures observed during holding tests in The Dalles Dam forebay, 1985.

Date	Percent mortality in cages positioned at the indicated depth (m)[a]								Dissolved gas conc.[b] percent of saturation			Water temp. °C
	Hatchery fish				River-run fish							
	0-1	1-2	3-4	0-6.1	0-1	1-2	3-4	0-6.1	low	1300 h	high	
					Yearling chinook salmon							
5/13	Introduced 1500 h				Introduced 1700 h				106	-	111	11.4
5/14	0	0	-	0	10	0	-	0	105	105	118	11.4
5/15	0	0	-	0	5	2	-	0	106	107	116	11.4
5/16	0	0	-	0	0	0	-	0	109	109	113	11.5
5/17	0	0	-	0	0	0	-	2	108	110	111	12.5
5/18	0	1	-	0	2	0	-	0	110	110	111	12.9
Total	0[c]	1	-	0	17[c]	2	-	2	Weighted avg. 110.1			Avg. 11.9
5/20	Introduced 1500 h				Introduced 1700 h				108	-	108	13.5
5/21	0	0	0	0	0	0	0	4	107	107	109	13.7
5/22	0	0	0	0	0	12	15	0	109	109	109	14.3
5/23	0	0	0	0	2	0	0	0	109	110	110	14.3
5/24	0	0	0	0	2	0	0	0	109	109	112	14.8
5/25	0	0	0	0	0	0	5	0	106	106	110	14.8
Total	0	0	0	0	4	12	20	4	Weighted avg. 109.0			Avg. 13.9
5/28	Introduced 1500 h				Introduced 1600 h				109	-	109	14.9
5/29	0	2	0	2	5	0	5	5	106	106	109	15.0
5/30	0	0	2	2	0	-	0	0	106	106	109	15.1
5/31	0	0	0	0	0	-	0	0	106	106	109	15.3
6/01	0	0	0	0	0	-	0	0	106	106	109	15.0
6/02	0	0	2	0	0	-	5	5	104	104	108	14.9
Total	0	2	4	4	5	0	10	10	Weighted avg. 108.1			Avg. 15.0

Table 2.--continued.

	Percent mortality in cages positioned at the indicated depth (m)[a] Hatchery fish				River-run fish				Dissolved gas conc.[b] percent of saturation			Water temp. °C
Date	0-1	1-2	3-4	0-6.1	0-1	1-2	3-4	0-6.1	low	1300 h	high	
					Subyearling chinook salmon[d]							
7/08	Introduced 1500 h								99	-	100	20.3
7/09	-	-	-	0	Introduced 1330 h				99	99	99	20.4
7/10	-	-	-	0	-	-	-	16	99	99	99	20.4
7/11	-	-	-	0	-	-	-	0	99	99	100	20.5
7/12	-	-	-	0	-	-	-	1	99	99	99	20.6
Total				0				17	Weighted avg. 99.1			Avg. 20.4
7/22	Introduced 1600 h				Introduced 1600 h				-	-	-	21.5
7/23	-	-	-	1	-	-	-	0	-	-	-	21.5
7/24	-	-	-	3	-	-	-	0	-	-	-	21.6
7/25	-	-	-	0	-	-	-	0	-	-	-	22.1
7/26	-	-	-	3	-	-	-	-	-	-	-	22.4
Total				7				0	Range 99-102[e]			Avg. 21.8
8/12	Introduced 0900 h				Introduced 0900 h				-	-	-	-
8/13	-	-	-	0	-	-	-	0	-	-	-	21.5
8/14	-	-	-	0	-	-	-	0	-	-	-	21.5
8/15	-	-	-	0	-	-	-	0	-	-	-	-
Total				0				0	Range 99-102[e]			Avg. 21.5

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[a] Percent of the number of individuals at the start of testing (about 50).

[b] Dissolved gas concentrations within the 24-h period; lowest, highest, and at 1300 h (the aproximate time of the vertical distribution observation).

[c] Signs of gas bubble disease were not observed in any held fish. It is doubtful that signs could have been observed by SCUBA divers on fish swimming in the cages. If signs were present in fish on 14 and 15 May, it seems likely that none would have been observable by the end of that test when fish were examined individually at the surface.

[d] Fish were not held at 0-1 m, 1-2 m, and 3-4 m because dissolved gas concentrations were not expected to go above 105% of saturation.

[e] Extrapolated from measurements at John Day Dam.

Table 2.--continued.

Date	Percent mortality in cages positioned at the indicated depth (m)[a] Hatchery fish 0-1	1-2	3-4	0-6.1	River-run fish 0-1	1-2	3-4	0-6.1	Dissolved gas conc.[b] percent of saturation low	1300 h	high	Water temp. °C
					Subyearling chinook salmon[d]							
7/08	Introduced 1500 h								99	-	100	20.3
7/09	-	-	-	0	Introduced 1330 h				99	99	99	20.4
7/10	-	-	-	0	-	-	-	16	99	99	99	20.4
7/11	-	-	-	0	-	-	-	0	99	99	100	20.5
7/12	-	-	-	0	-	-	-	1	99	99	99	20.6
Total				0				17	Weighted avg. 99.1			Avg. 20.4
7/22	Introduced 1600 h				Introduced 1600 h				-	-	-	21.5
7/23	-	-	-	1	-	-	-	0	-	-	-	21.5
7/24	-	-	-	3	-	-	-	0	-	-	-	21.6
7/25	-	-	-	0	-	-	-	0	-	-	-	22.1
7/26	-	-	-	3	-	-	-	-	-	-	-	22.4
Total				7				0	Range 99-102[e]			Avg. 21.8
8/12	Introduced 0900 h				Introduced 0900 h				-	-	-	-
8/13	-	-	-	0	-	-	-	0	-	-	-	21.5
8/14	-	-	-	0	-	-	-	0	-	-	-	21.5
8/15	-	-	-	0	-	-	-	0	-	-	-	-
Total				0				0	Range 99-102[e]			Avg. 21.5

[a] Percent of the number of individuals at the start of testing (about 50).

[b] Dissolved gas concentrations within the 24-h period; lowest, highest, and at 1300 h (the aproximate time of the vertical distribution observation).

[c] Signs of gas bubble disease were not observed in any held fish. It is doubtful that signs could have been observed by SCUBA divers on fish swimming in the cages. If signs were present in fish on 14 May and 15 May, it seems likely that none would have been observable by the end of that test when fish were examined individually at the surface.

[d] Fish were not held at 0-1 m, 1-2 m, and 3-4 m because dissolved gas concentrations were not expected to go above 105% of saturation.

[e] Extrapolated from measurements at John Day Dam.

examined out of water. Gas bubbles disappear relatively quickly at low dissolved gas levels (Dawley et al. 1976). Supersaturation during other tests (maximum of 112%) was not high enough to cause GBD in 8-h periods, even in the 0- to 1-m cage.

Mortality levels for fish held in the upper meter of the water column were not statistically greater (t=0.04, P>0.05, df=20) than for other groups held at greater depths, which allowed for greater hydrostatic pressure compensation (Table 2). On the first day of testing, 10% mortality of river-run fish occurred in the 0- to 1-m cage, but this was before dissolved gas levels reached 118% of saturation; GBD signs were not observed in dead fish from that cage. We assume stress from collection in the gatewell, transport, placement in the cage, and jostling of the cages by wave action on the flotation raft caused the mortality.

Results of the 1985 holding study compare favorably with laboratory studies on effects of supersaturation, and these results complement previous in situ evaluations in the Columbia River. Laboratory studies conducted in water depths <0.6 m, which provided little hydrostatic pressure compensation, showed that migrant-sized juvenile salmonids developed no GBD signs when saturations were 110% or less; at 115%, signs developed and mortality began in a few days (Dawley et al. 1976; Dawley and Ebel 1975; and Nebeker 1973; Meekin and Turner 1974). Tests with greater water depth availability (2.5 m) decreased GBD incidence and associated mortality. Effects were similar to those in shallow water tests at 10% lower supersaturation (Dawley et al. 1976). Previous in situ holding tests, evaluating effects of supersaturation in reservoirs, showed that test fish which were allowed access to water depths sufficient to alleviate GBD through hydrostatic pressure compensation, exhibited substantially less mortality than fish confined to surface levels (Ebel 1971; Weitkamp 1976).

Previous intermittent exposure tests showed that diel periods at low dissolved gas levels provided substantial benefit from the effects of supersaturation (Weitkamp 1976; Blahm et al.1976); internal gas pressures of test fish apparently decreased during the low level periods. Both investigations showed that subyearling chinook salmon suffered little mortality when subjected to 8 h of high dissolved gas levels (124 and 130%) and 16 h of low levels (≤100%). The larger yearling chinook salmon tested at The Dalles Dam in 1985 are probably less tolerant to supersaturation because of size (Dawley et al. 1976); however, the fluctuating supersaturation at these somewhat lower levels also caused no detrimental effects.

Dissolved gas concentrations (99 to 102%) during tests of subyearling fish were not high enough to cause GBD. Therefore, tests were conducted only in volitional cages to examine vertical distribution at ambient levels of dissolved gas saturation.

Adults were not examined because of the low supersaturation levels.

Vertical Distribution.--Detection and avoidance of supersaturation were observed in previous tests with juvenile chinook salmon (Dawley et al. 1975; Blahm et al. 1976). Mortality was substantially reduced but not eliminated by apparent lateral and vertical avoidance. Juvenile steelhead tested in similar conditions generally did not show an avoidance reaction.

During holding tests with yearling chinook salmon, signs of GBD were not observed, even in the 0- to 1-m cages. Thus, we hypothesized that stress to fish from supersaturation in the volitional cage (0-6.1 m) was low, and the effects on the depth distribution of test fish were minimal. Mean depths of fish for each 5-day test period ranged from 3.6 to 4.3 m (Table 3). About 2% of the fish were observed at 0 to 1.2 m and 9% at 1.2 to 2.4 m of depth. Statistical evaluation of differences in vertical distribution between hatchery and river-run fish, the three replicate test series, and daily observations showed no significant differences ($P < 0.05$); three way ANOVA ($f=0.05$ $df=1,18$; $f=0.29$ $df=2,18$; $f=0.92$ $df=2,18$).

Vertical distributions of subyearling chinook salmon were consistent through the three series of tests; mean depths in the volitional cages ranged from 3.1 to 4.0 m (Table 3). About 6% of the fish were observed at 0 to 1.2 m and 15% at 1.2 to 2.4 m of depth. There were no significant differences among mean depths of subyearlings ($t=0.27$, $P<0.05$, $df=11$). Ebel[3/] observed that subyearlings, in volitional cages at Priest Rapids Dam reservoir, congregated at 2.5 to 3.5 m of depth at both high supersaturation (143%, where mortality was 0%) and low supersaturation (118%, where mortality was 6%).

Future comparisons of vertical distribution during high supersaturation are necessary to evaluate whether fish will alter their depth distribution to counteract supersaturation stress. Vertical distributions of yearling and subyearling fish observed in 1985 can be used as a quasi-control.

Hydroacoustic Observations

Vertical distribution of salmonids in front of The Dalles Dam was assessed by BioSonics, Inc. using hydroacoustic techniques. Fifty percent of the yearling chinook salmon observed were within 4.6 m of the surface

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[3/] W. J. Ebel, Biologist, National Marine Fisheries Service, 2725 Montlake Blvd. E., Seattle, WA 98112, unpublished data.

Table 3.--Vertical distributions of yearling and subyearling chinook salmon held in cages in The Dalles Dam forebay, 1985; percent of fish at depth interval.

	Hatchery fish						River-run fish					
	Depth interval (m)					Mean depth (m)	Depth interval (m)					Mean depth (m)
Date	0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1		0-1.2	1.2-2.4	2.4-3.7	3.7-4.9	4.9-6.1	
						Yearling chinook salmon						
5/14	0	40	50	0	10	2.8	0	0	0	100	0	4.3
5/15	2	3	28	49	18	4.0	5	10	48	30	8	3.4
5/16	0	5	25	50	20	4.1	2	14	34	45	5	3.5
5/17	0	0	4	45	51	4.9	0	5	14	47	34	4.4
Avg.	1	12	27	36	25	4.1	2	7	24	55	12	3.9
5/21	0	4	38	57	2	3.8	0	25	25	50	0	3.4
5/22	6	0	27	55	12	3.9	0	0	6	45	49	4.8
5/23	8	17	0	42	33	4.0	0	0	17	42	42	4.6
5/24	0	6	31	31	31	4.1	0	5	14	38	43	4.5
Avg.	4	7	24	46	20	3.9	0	7	15	44	33	4.3
5/29	0	20	40	40	0	3.3	0	40	60	0	0	2.5
5/30	0	0	0	100	0	4.3	4	0	0	75	21	4.4
5/31	4	0	8	58	38	4.5	0	8	31	62	0	3.7
6/01	3	0	13	37	47	4.6	0	17	19	28	36	4.1
Avg.	2	5	15	59	29	4.1	1	16	27	41	14	3.6

Table 3.--continued.

	Hatchery fish						River-run fish					
	Depth interval (m)					Mean	Depth interval (m)					Mean
Date	0- 1.2	1.2- 2.4	2.4- 3.7	3.7- 4.9	4.9- 6.1	depth (m)	0- 1.2	1.2- 2.4	2.4- 3.7	3.7- 4.9	4.9- 6.1	depth (m)
						Subyearling chinook salmon						
7/09	6	21	29	34	10	3.3	-	-	-	-	-	-
7/10	10	11	26	37	15	3.5	0	5	36	36	23	4.0
7/11	0	3	16	40	40	4.5	7	19	19	28	28	3.7
7/12	2	6	31	31	31	4.1	2	0	20	39	39	4.4
Avg.	5	10	26	36	24	3.9	3	8	25	34	30	4.0
7/23	0	25	25	25	25	3.7	0	0	43	29	29	4.1
7/24	11	22	22	22	22	3.3	4	14	27	27	27	3.7
7/25	14	21	21	21	21	3.8	2	21	35	28	14	3.4
7/26	6	19	25	25	25	3.6	-	-	-	-	-	-
Avg.	8	22	23	23	23	3.4	2	12	35	28	23	3.7
8/13	11	7	25	25	32	3.8	-	-	-	-	-	-
8/14	12	12	23	27	27	3.6	14	50	29	3	4	2.2
8/15	0	4	27	32	37	4.3	0	0	41	35	24	4.1
Avg.	13	13	25	28	30	3.9	7	25	35	19	14	3.1

(Steig and Johnson 1986). Subyearlings were deeper; 50% were within 9.1 m of the surface at the powerhouse and within 5.8 m of the surface at the spillway. We estimate that the danger zone for salmonids, during high supersaturation, is 0-3 m depth; hydrostatic pressure below 3 m reduces the ambient supersaturation to tolerable levels for salmonids for most conditions encountered in the Columbia River. The percentages of migrants above 3 m at the powerhouse and spillway were: 22 and 8%, respectively, for yearling fish, and 10 and 15%, respectively, for subyearling fish. Both age classes had deeper vertical distributions during the night. Relative differences of vertical distribution associated with time of day and age class were consistent with observations at other Columbia River dams (Raemhild et al. 1984a, 1984b).

Hydroacoustic observations of migrant depth at dams do not necessarily represent distributions of fish migrating through the reservoir, nor of fish hesitating in front of the dam. Many targets observed by the echo sounders are fish in the process of passing into the turbines or under spill gates (T. Steig[4/]).

Daytime observations made by NMFS from a small boat traversing the reservoir 50 to 300 m upstream from The Dalles Dam were not very successful. Only 43 targets were observed--all yearling fish in May. Combined data from the surveys indicated that 48% of fish were in the upper meter, 32% from 1 to 2 m, 7% from 2 to 3 m, and 13% below 3 m in depth. The expansion factors used to adjust for area of the echo sounding cone at the

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[4/] T. Steig, BioSonics, Inc., 4520 Union Bay Place, Seattle, WA 98112, pers. commun. 1986.

first and second meter depth were very large and the targets very few, resulting in questionable data.

In round-the-clock hydroacoustic observations made near the shoreline upstream from the dam, 32% of the 108 targets were in the upper 3 m in daylight and 27% of the 64 targets in the upper 3 m at night. These observations, made in May and early June, presumably represent yearling salmonids; however, resident fishes may have influenced these observed depth distributions. The few subyearling fish observed do not warrant a report.

1986

Dissolved Gas Levels

Warm weather in late May caused a rapid snowmelt, leading to unexpected high flows in the Snake and mid- and lower-Columbia Rivers. From 30 May to 8 June, about 34% of the flow at Lower Granite Dam on The Snake River and 41% of the flow at Priest Rapids Dam on the Columbia River were spilled (Fig. 6); total flows averaged 194 and 160 kcfs, respectively, at the two dams. Consequently, dissolved gas levels increased to $\geq$120% through hundreds of miles of river (Fig. 6). Large diurnal fluctuations in gas concentrations, as observed in 1985, did not occur because water was spilled 24 h per day.

Gas Bubble Disease in Migrants

In the 8-day period of evaluation, 1-9 June, signs of GBD, predominately cutaneous bubbles between the rays of one or two fins, were observed in migrating juvenile salmonids (Table 4). From past research, we believe these signs were caused by short-term exposure to high levels of supersaturation (hours at > 115%) or long-term exposure at low levels of supersaturation (days at < 115%). The majority of observed migrants must have been at depths sufficient to keep the effective gas pressure in their bodies below 115%

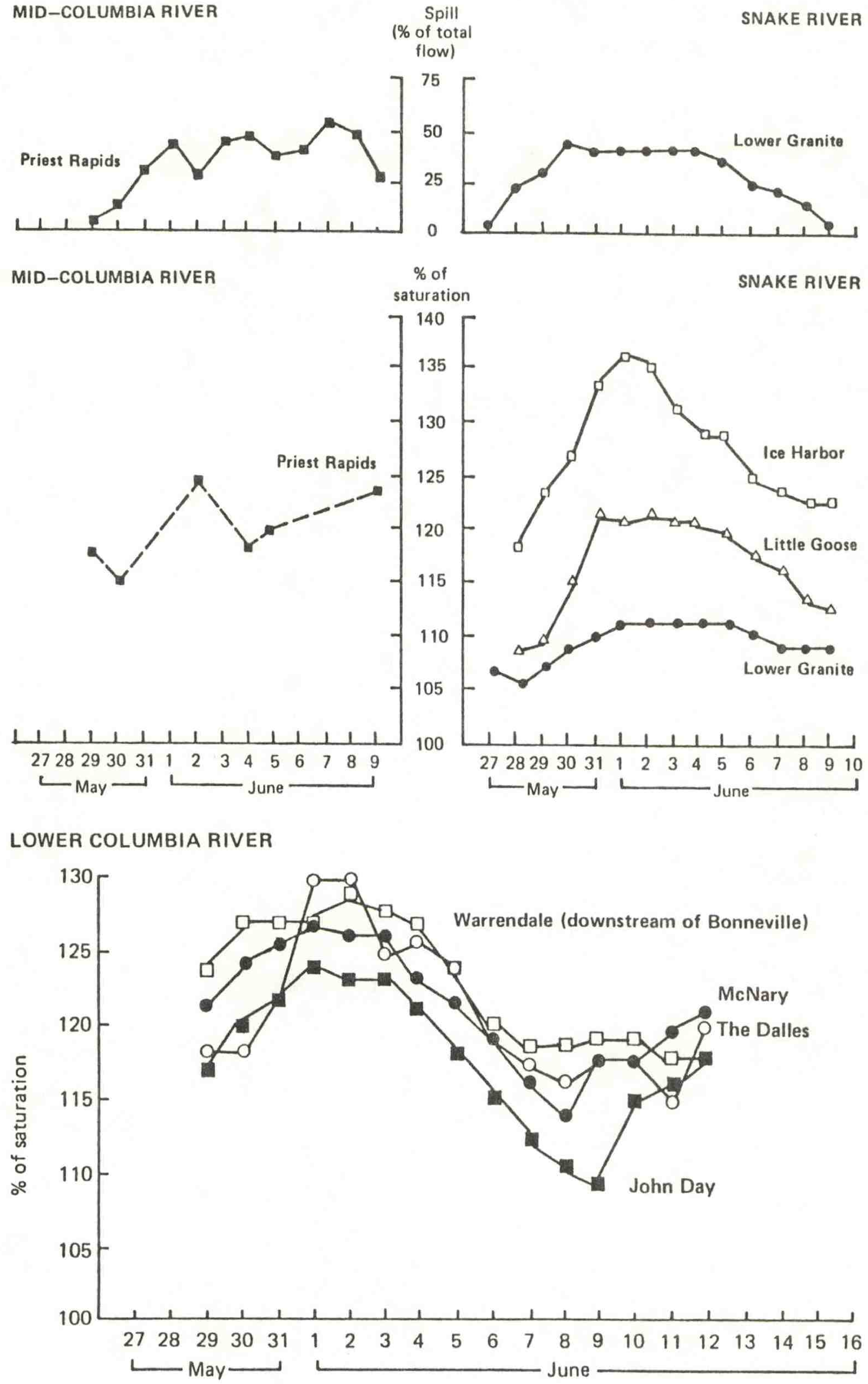

Figure 6.--Percentages of river flow spilled at Lower Granite Dam (Snake River) and Priest Rapids Dam (Columbia River) in May-June 1986. Dissolved gas levels at eight sites are also shown.

Table 4.--Incidence of gas bubble disease in juvenile salmonids sampled at McNary, John Day, and Bonneville Dams, 1986 (usually 100 or more individuals/sample).

	Percent with signs of gas bubble disease[a]														
	Steelhead			Subyearling chinook salmon			Yearling chinook salmon			Coho salmon			Sockeye salmon		
Date	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.	McNary	John Day	Bonn.
1 June	4	-[b]	-	0	-	-	7	-	-	3	-	-	2	-	-
2	3	0	3	0	0	0	3	0	0	0	0	0	0	0	0
3	4	0	14(2)	0	0	0	1	0	0	5	0	0	0	0	0
4	2	0	16(2)	0	0	0	<1	0	0	1	0	0	0	0	0
5	2	0	13(1)	0	0	0	2	0	0	0	0	1	0	0	0
6	3	0	-	0	0	-	2	0	-	0	0	-	0	0	-
7	1	0	-	0	0	-	1	0	-	0	0	-	0	0	-
8	2	0	0	0	0	0	<1	0	0	0	0	0	0	0	-
9	1	0	0	0	0	0	<1	0	0	0	0	0	0	0	0

[a] Signs were primarily bubbles in fins--few in number. Profuse bubbles in fins, in mouth, or on head (indicating more severe stress) were observed only at Bonneville Dam; percent incidence denoted by the numbers in ( ).

[b] No observations are indicated by a dash (-).

(>1 m; assuming an average 125% of saturation). Only juvenile steelhead at Bonneville Dam showed substantial signs of GBD (13-16% of individuals examined during a 3-day period); about 2% had severe signs (massive areas of bubbles in fins, on the operculum, or in the buccal cavity).

At McNary Dam, adult chinook salmon and steelhead were examined for GBD during the high flow period. Signs of GBD were not observed in any of the 28 fish examined.

CONCLUSIONS AND RECOMMENDATIONS

During 1985 and 1986, the impacts of supersaturation in the lower Columbia River (McNary Dam to the estuary) were minimal to juvenile and adult salmonids. Juvenile steelhead were affected most, but probably did not suffer substantial mortality because of their rapid movement to the ocean (Dawley et al. 1986).

Salmonid's tolerance to supersaturation and their ability to detect and avoid supersaturation seem dependent on life stage, species, stock, and environment (Dawley and Ebel 1975; Alderdice and Jensen 1985; and Lund and Heggberget 1985). Lethal conditions may prevail in certain areas at certain times, so knowledge of the tolerance limits for resident and migrant fishes impacted by supersaturation is essential to assess the necessity for counteractive measures.

Future studies at The Dalles Dam during a period of high supersaturation are necessary to satisfy the objectives of this study.

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