

**EFFECTS OF DISSOLVED GAS SUPERSATURATION ON FISH RESIDING IN THE
SNAKE AND COLUMBIA RIVERS, 1996**

by

Boyd P. Schrank
Brad A. Ryan
and
Earl M. Dawley

Research Funded by
Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208-3621
(Contract 96-BI-93605)
Project NO. 96-022

and

Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

March 1998

EFFECTS OF DISSOLVED GAS SUPERSATURATION ON FISH RESIDING IN THE SNAKE AND COLUMBIA RIVERS, 1996

ABSTRACT

Spill at Columbia and Snake River Dams, intended to provide safe passage for migrating juvenile salmon, has commonly caused dissolved gas levels to exceed state and federal water quality criteria. Total dissolved gas supersaturation (TDGS) resulting from spill in past decades led to gas bubble disease (GBD) in fish. Therefore, during the period of high spill in 1996, we monitored the prevalence and severity of GBD by sampling feral fish in the Columbia River upstream and downstream from Priest Rapids Dam (RKm 650 - 642 and 624 - 592, respectively) and downstream from Bonneville Dam (RKm 229 - 219) and in the Snake River downstream from Ice Harbor Dam (RKm 14 to 2). Additionally, subsamples of nonsalmonid fish species were held in 4-m deep net-pens for 4 days and then reexamined for prevalence and severity of GBD.

Between 15 March and 17 August, we examined 1,172 salmonids, 9,905 non-salmonid juveniles and adults, and 1,227 non-salmonid fry for signs of GBD. In general, we observed GBD signs in juvenile and adult fish collected within the sample areas when average daily TDGS exceeded 120%, and high prevalence (13.7-37.8%) when TDGS peaked at 130-142%. Severe signs of GBD were observed in 14.3% of all fry sampled downstream from Bonneville Dam.. We initiated development of a model describing GBD prevalence in relation to TDGS in the sampled river reaches.

Resident nonsalmonid fish taken from the river for pen studies, often had signs of GBD at introduction to the pens. After 4 days of holding, GBD signs among these captive fish usually persisted and generally showed an increase in prevalence. When TDGS dropped below 120%, we observed low prevalence of GBD signs and no GBD related mortalities in captive fish.

EXECUTIVE SUMMARY

Increased spill at dams has commonly brought dissolved gas supersaturation higher than levels established by state and federal water quality criteria in the Columbia and Snake Rivers. These increased spill volumes are intended to provide safe passage for migrating juvenile salmon. However, dissolved gas supersaturation resulting from spill in past decades has led to gas bubble disease (GBD) in fish. Therefore, during the period of high spill in 1996, we monitored the prevalence and severity of gas bubble disease by sampling resident fish in Priest Rapids Reservoir and downstream from Bonneville, Priest Rapids, and Ice Harbor Dams.

We made non-lethal visual examinations of fish using 2.5- to 5-power magnification lenses to assess external signs of GBD (subcutaneous emphysema on fins, head, eyes, and body surface). Subsamples of 5 to 10 resident fish from each sampling day were examined more closely with 20-power magnification for gas bubbles in the lateral line, brachial arteries, and gill lamellae.

Subsamples of resident nonsalmonid fish species were held in pens for 4 days and then examined for prevalence and severity of GBD. Three types of pens were used: surface cages held at a depth of 0 to 0.5 m, deep submerged cages held at a depth of 2 to 3 m, and large net-pens with a sloping bottom that extended from the surface to a depth of 4 m.

Gas Bubble Disease Signs in Resident Fish

Between 15 March and 17 August, we examined 1,172 salmonid fishes, 1,227 non-salmonid fry, and 9,905 non-salmonid fishes for signs of GBD. Signs of GBD in fish were prevalent downstream from Ice Harbor Dam and in Priest Rapids Reservoir. In other reaches,

downstream from Bonneville and Priest Rapids Dams, signs of GBD were less prevalent.

State and federal water quality criteria set total dissolved gas saturation (TDGS) of 110% as the maximum acceptable level. From 1 to 15 km downstream from Bonneville Dam, TDGS reached 139.9%, and daily average TDGS remained above 125% from 30 May to 20 June. Spill as high as 259,600 ft³/sec and 64.5% of total river flow occurred. On 13 June, prevalence of GBD signs among individual daily fish samples reached 15.8%. Signs of GBD were observed in 14.3% of all fry sampled downstream from Bonneville Dam.

From 15 to 47 km downstream from Priest Rapids Dam (Hanford Reach), TDGS reached 130%, and daily averages remained above 120% from 24 May to 21 July. Spill as high as 132,500 ft³/sec and 50.8% of total river flow occurred, though prevalence of GBD signs among daily samples never exceeded 15%.

In Priest Rapids Reservoir (downstream from Wanapum Dam), TDGS reached 136% and daily averages remained above 125% from 27 May to 24 June as a result of freshet flow past Wanapum Dam. Spill as high as 131,600 ft³/sec and 50.1% of total river flow occurred. Prevalence of GBD signs among individual daily fish samples reached 23.1% on 27 May and 16.7% on 3 June.

From 1.6 to 13.7 km downstream from Ice Harbor Dam, TDGS reached 142%, and daily averages almost always exceeded 130% from 1 April to 30 April and from 15 May to 24 June as a result of freshet flows and turbine outages at Ice Harbor Dam. Because of high flow and limited turbine capacity, spill as high as 116,900 ft³/sec and 60.9% of total river flow occurred. Prevalence of GBD signs within individual daily fish samples was greater than 30% on several occasions (30 May, 6 June, 11 June, and 20 June).

Gas Bubble Disease in Captive Fish

Resident nonsalmonid fish used for the net-pen studies were taken from the river and often had signs of GBD at introduction to the pens. After 4 days of holding, GBD signs among the captive fish usually persisted and generally showed an increase in prevalence.

Downstream from Bonneville Dam, fish held in the 0- to 4-m pen showed external GBD signs in 7 of the 13 holding periods; prevalence of external GBD signs ranged from 0 to 58.4%. Prevalence of external GBD signs increased during every 4-day holding period between 17 May and 24 June. When prevalence of external GBD signs increased, mortality ranged from 0 to 4%.

Upstream from Priest Rapids Dam, fish held in the 0- to 4-m pen showed increases of external GBD signs in 15 of the 16 holding periods; prevalence of external GBD signs ranged from 0 to 70.0%. When prevalence of external GBD signs increased, mortality ranged from 0 to 33%.

Downstream from Ice Harbor Dam, fish held in the 0- to 4-m pen showed increases of external GBD signs in 9 of the 13 holding periods; prevalence of external signs ranged from 0 to 86.0%. When prevalence of external signs of GBD increased, mortality ranged from 4 to 33%.

Model of Gas Bubble Disease Impacts

In general, we observed high prevalence of GBD signs in fish collected within the sample areas when average daily TDGS exceeded 120%. When TDGS dropped below 120%, we observed low prevalence of GBD signs in sampled fish and low mortalities in captive fish.

Our goal was to provide fishery managers with a definition of TDGS impacts to resident fish throughout affected areas in the Columbia and Snake Rivers. We used sampling and previous

research data to develop a model providing an estimation of GBD impacts. For the model we attempted to use all data from current and previous study years to predict mortality of resident fish resulting from high TDGS. Unfortunately, mortality in resident fish populations could not be properly evaluated through sampling because dead fish can rarely be recovered from the river. Thus, it was necessary to use captive fish to assess mortality. Our first step in developing the model was to analyze the relationship between external GBD signs and TDGS exposure in resident fish. The second step was based on our holding experiments, where we examined the relationship between external GBD signs and mortality.

A mathematical equivalence for increasing, static, and decreasing exposure to TDGS from the Columbia River Operations Hydro-met System was used to develop an exposure index (EI). The EI was correlated with external signs of GBD among resident fish. Correlation was assessed using the following equation for mathematical equivalence and second-order polynomial regression: $\%GBD \text{ signs} = 0.05(EI)^2 + 0.21(EI) + 0.62$, $R^2 = 0.79$. Unfortunately our ability to predict mortality was poor, since there was no clear correlation between external GBD signs and mortality in captive fish when data from all species were combined. Data from three resident species (smallmouth bass, yellow perch, and peamouth) produced a stronger correlation; however these relationships were not statistically significant.

Recommendation

Sampling and holding experiments should be continued in river reaches where TDGS exceeds 120%. To supplement data in the mortality model, the efforts should focus on three species: smallmouth bass, yellow perch, and peamouth.

CONTENTS

EXECUTIVE SUMMARY	iii
Gas Bubble Disease Signs in Resident Fish	iii
Gas Bubble Disease in Captive Fish	v
Model of Gas Bubble Disease Impacts	v
INTRODUCTION	x
METHODS	4
Sampling Locations	4
Sampling Methods	4
Net-pen Studies	9
Dissolved Gas Measurements	10
Gas Bubble Disease Effects Model	12
RESULTS	14
Signs of Gas Bubble Disease in Resident Fish	14
Downstream from Bonneville Dam	14
Downstream from Priest Rapids Dam	14
Priest Rapids Reservoir	22
Downstream from Ice Harbor Dam	28
Gas Bubble Disease in Captive Fish Groups	32
Downstream from Bonneville Dam	32
Priest Rapids Reservoir	36
Downstream from Ice Harbor Dam	41
Gas Bubble Disease Effects Model	45
Exposure vs. Gas Bubble Disease Signs	45
Gas Bubble Disease Signs vs. Mortality	49
DISCUSSION	51
Comparison to 1995 GBD Study	51
Gas Bubble Disease Effects Model	52
CONCLUSIONS AND RECOMMENDATIONS	53
ACKNOWLEDGEMENTS	54
REFERENCES	55
APPENDICES	58

INTRODUCTION

In recent years, spill has been used to increase survival of juvenile salmonids (*Oncorhynchus* spp.) passing through Columbia and Snake River dams. Many studies have concluded that spill provides the safest route for juvenile salmonids passing dams on the Columbia and Snake Rivers. However, increased use of spill has raised concern that the resulting increase in dissolved gas levels of the water may be detrimental to aquatic biota. Supersaturation of dissolved atmospheric gases can lead to gas bubble disease (GBD), which is potentially lethal to fish and invertebrates.

During the 1996 spring freshet, dissolved gas levels in the Columbia and Snake Rivers often exceeded 110% of saturation, the maximum level permitted by the U.S. Environmental Protection Agency, Washington State Department of Ecology, Idaho Department of Environmental Quality, and Oregon State Department of Environmental Quality. The highest levels of supersaturation during this period resulted from conditions over which there was no control, such as high springtime river flows combined with turbine outages at some dams. However, some supersaturation occurred as a result purposeful spill for enhanced fish passage.

In 1994, 1995, and 1996, the U.S. Army Corps of Engineers (COE) obtained a temporary variance for the 110% saturation maximum standard from the Washington State Department of Ecology and Oregon State Department of Environmental Quality to accommodate spillway passage of juvenile salmon. Dissolved gas levels in tailraces at most dams on the lower Snake and Columbia Rivers were allowed to reach 120% of saturation. An intensified GBD monitoring program was instituted for juvenile salmonids at the dams to evaluate the consequences of this action.

Many studies on GBD and its effect on salmonids have been conducted. From 1968 to 1975, GBD in high-flow years contributed to high mortalities of juvenile salmonids migrating from the Snake River (Ebel et al. 1975). The severity of GBD was dependent upon species, life stage, body size, level of total dissolved gas, duration of exposure, water temperature, general physical condition of the fish, and swimming depth (Ebel et al. 1975). Thorough reviews of the literature on dissolved gas supersaturation and of recorded cases of GBD were compiled by Weitkamp and Katz (1980) and updated by Fidler and Miller (1993). Despite numerous studies, there are still questions regarding the total dissolved gas saturation (TDGS) that salmonids can safely tolerate under natural conditions.

When it first became apparent that dissolved gas supersaturation of river water was due to spill at dams and that it caused serious problems for juvenile and adult fish in the Columbia and Snake Rivers, the COE devised methods to reduce dissolved gas supersaturation (Ebel et al. 1975). The methods investigated and implemented were 1) to increase headwater storage to control flow during the spring freshet, 2) to install additional turbines, and 3) to install flow deflectors ("flip-lips") below spillways to reduce air entrainment in spilled water. As a result of these remedial measures, there was little evidence of GBD in salmonids in the late 1970s and 1980s (Dawley 1986). However, as increased turbine capacity at dams helped reduce TDGS by allowing more river volume to pass through the powerhouse, it also increased the proportion of juvenile salmonids passing dams via turbines. Thus, passage survival at dams was decreased because survival for turbine passage is less than for spillway passage (Schoeneman 1961).

To improve survival of downstream migrating juvenile salmonids, the present program of

increased spill was implemented in the 1980s. This spill program resulted in diurnal fluctuations of dissolved gas levels, and in 1985 and 1986 signs of GBD were observed in juvenile and adult salmonids in the Columbia River at McNary, John Day, The Dalles, and Bonneville Dams (Dawley 1986). However, based on low prevalence of GBD signs, it appeared that impacts of dissolved gas supersaturation were minimal, probably because of the short duration of high supersaturation levels. In addition, these high levels of dissolved gas resulted from flows exceeding hydro-capacity, not from purposeful spill for enhanced fish survival.

The effects of dissolved gas supersaturation on aquatic biota other than salmonids are not fully understood. Most research has focused on trout and salmon (Weitkamp and Katz 1980), and studies that focused on the occurrence of GBD in resident fish in situ (Dell et al. 1974) were conducted before the implementation of the current spill regime, with its resulting diurnal fluctuations. These earlier studies were also conducted before the availability of meters, which allow continuous recording of dissolved gas saturation levels.

The objectives of this study were to assess impacts of ambient levels of gas supersaturated water on fish residing in the Columbia and Snake Rivers and to develop a model that can be used in "real time" by fisheries managers to predict mortality of resident fish resulting from dissolved gas supersaturation.

METHODS

Sampling Locations

Sampling in 1996 to assess impacts of GBD in resident fish species was conducted in the lower Columbia River downstream from Bonneville Dam, in the mid-Columbia River downstream and upstream from Priest Rapids Dam, and in the lower Snake River downstream from Ice Harbor Dam. Sampling downstream from Bonneville Dam, River Kilometer (RKm) 218.8 to RKm 229.1, was conducted from 15 March to 12 August (Fig. 1). In the mid-Columbia River, sampling was conducted 15 to 47 km downstream from Priest Rapids Dam (Hanford Reach), from 10 April to 8 August (Fig. 2), and in Priest Rapids Reservoir from 9 April to 12 August (Fig. 3). In the lower Snake River, sampling was conducted 1.6 to 13.7 km downstream from Ice Harbor Dam from 16 April to 15 August (Fig. 4).

Sampling Methods

Resident fish species were collected weekly from each river reach. Electrofishing from a boat equipped with a pair of adjustable booms fitted with umbrella anode arrays was the primary means of fish collection. All electrofishing used pulsed direct current at 30 pulses/second, 400-500 volts, and 1-2 amperes. A 7.5-m 2-stick seine with 12.7-mm webbing was also used in some shallow areas (less than 1 m deep), with two people pulling the seine upstream along the beach.

Downstream from Bonneville Dam, along shorelines having steep gradient, a 3.4-m-deep, 50-m variable-mesh beach seine was used to collect fish. The beach seine consisted of a 14.0-m panel of 19.0-mm mesh, a 17.1-m panel of 12.7-mm mesh, a 5.5-m panel of 9.5-mm mesh, and a 13.4-m panel of 19.0-mm mesh (all webbing sizes were stretch measure). For deployment, one

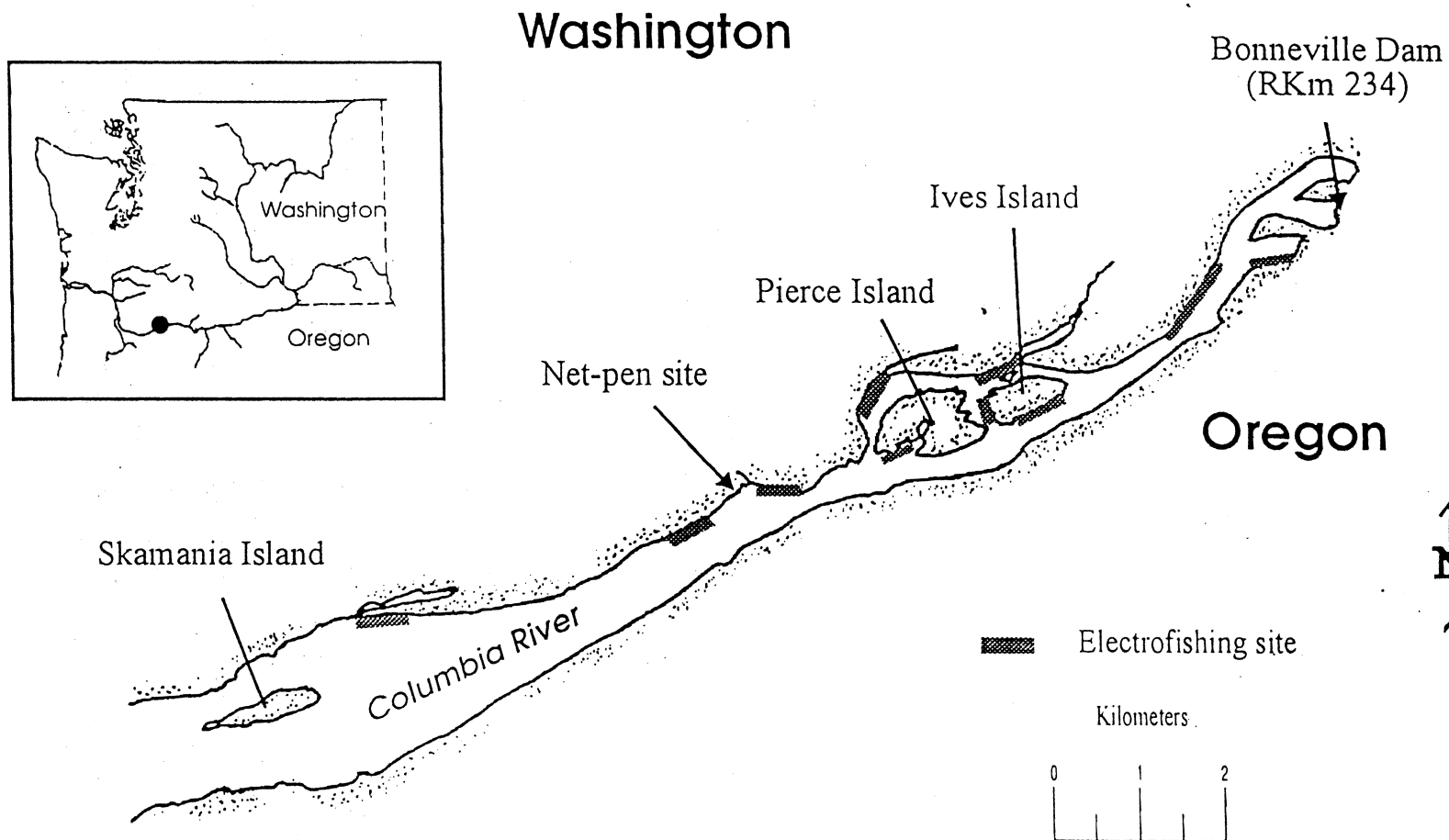


Figure 1. Sampling sites downstream from Bonneville Dam, 1996.

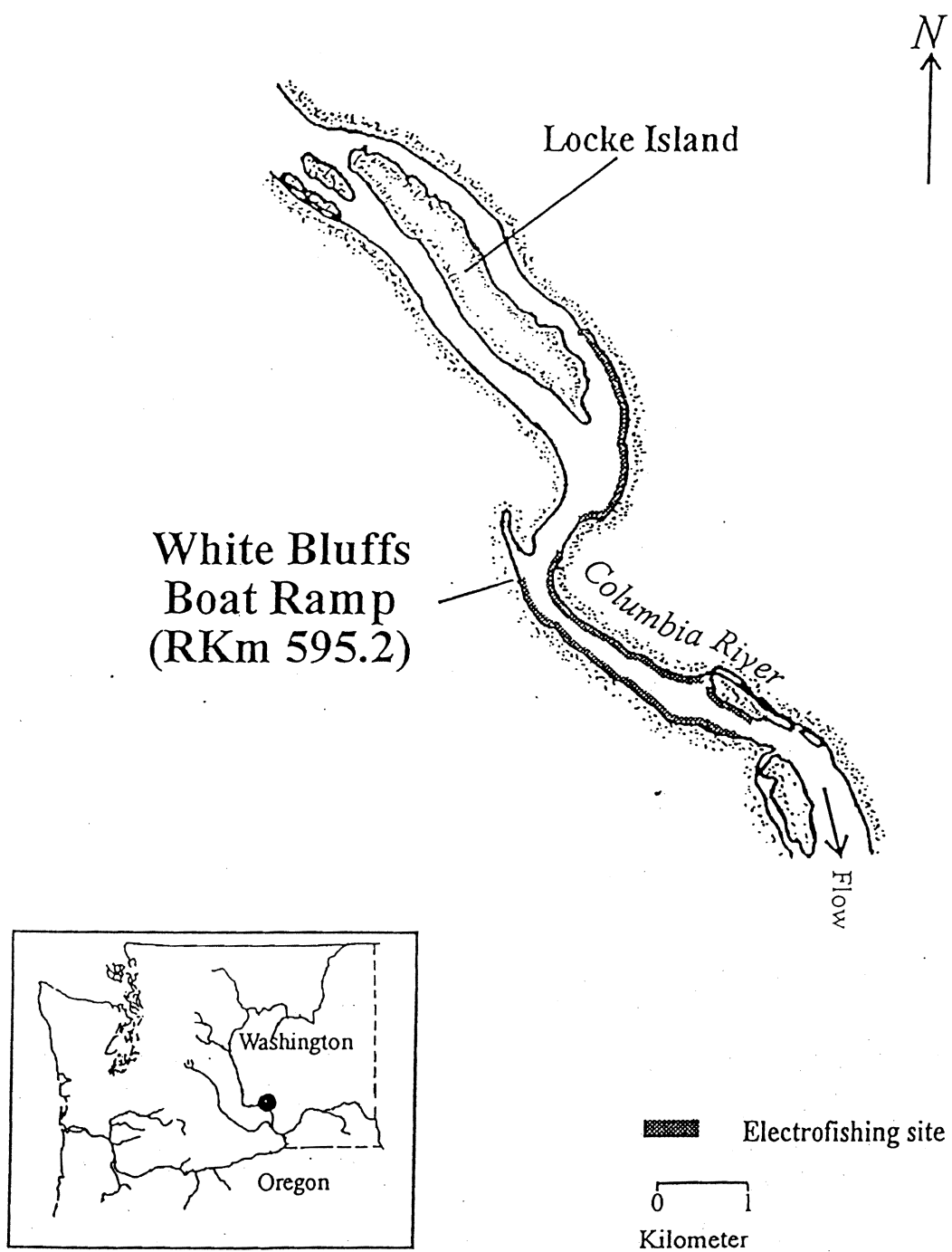


Figure 2. Sampling sites downstream from Priest Rapids Dam, 1996.

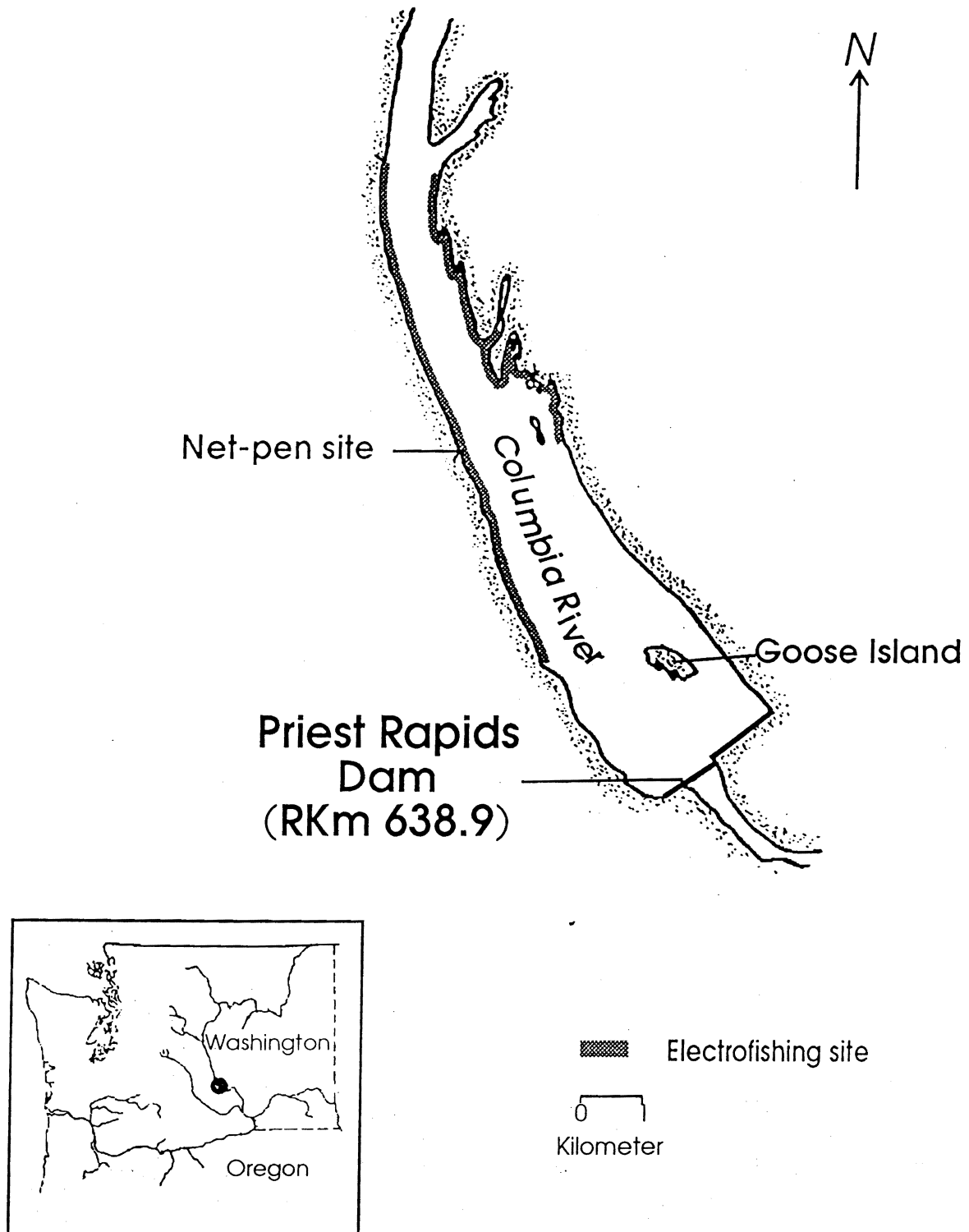


Figure 3. Sampling sites in Priest Rapids Reservoir, 1996.

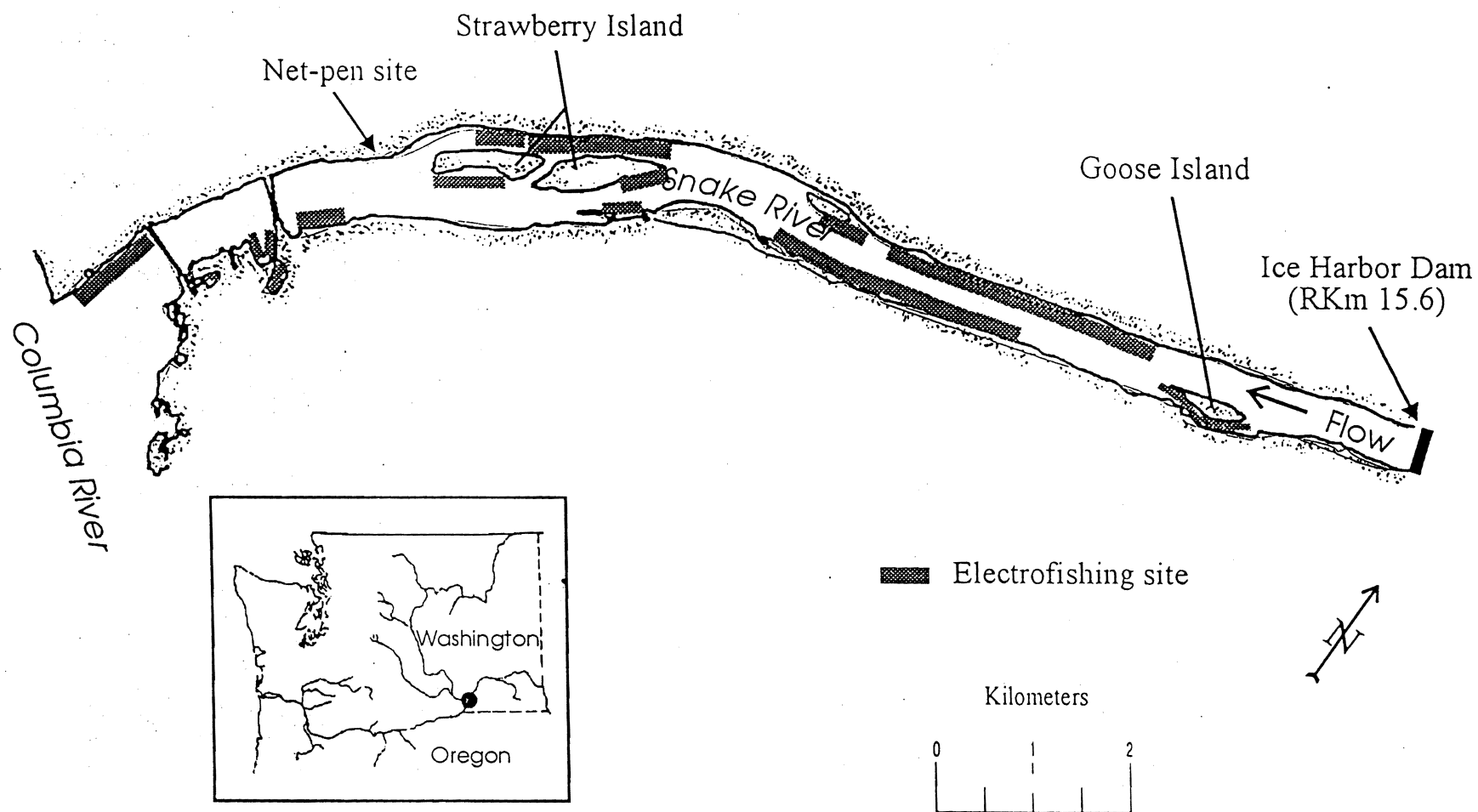


Figure 4. Sampling sites downstream from Ice Harbor Dam, 1996.

end of the seine was anchored on shore and the other was swung upstream in a wide arc using a 5-m outboard-powered boat. The seine was pulled onto the beach by hand, crowding captured fish into the bunt. A small hand-held aquarium net was also used to sample resident fry from near the water surface.

All captured fish were anesthetized using tricaine methane sulfonate (MS-222), identified, measured to the nearest millimeter, and examined for external injuries and signs of GBD (subcutaneous emphysema on fins, head, eyes, and body surface). Individual fish were examined externally using a 2.5- to 5-power headband magnifying lens. Internal examinations of fish were not conducted. Most examinations were made at sampling sites within 15 minutes of collection. During examinations, fish were held at ambient temperature and dissolved gas levels. All specimens were allowed to recover fully from the anesthetic prior to release or introduction into holding pens.

Net-pen Studies

Weekly observations of survival rates and changes in prevalence of GBD were made for resident nonsalmonid fish species. Specimens were collected from each river reach, examined for prevalence of GBD, held in enclosures for 4 days, and then reexamined for prevalence of GBD.

Three types of enclosures were used: shallow cages held at the surface, which provided a maximum depth of 0.5 m (0.6 x 0.6 x 1.0 m made of perforated aluminum-plate); deep submerged cages held from 2.0 to 3.0 m in depth (0.6 x 0.6 x 1.0 m made of perforated aluminum-plate), and large net-pens (1.8 x 2.44 m) with an inclined bottom that extended from the surface to 4 m.

Built into each net-pen was a webbing partition extending from the water surface to the bottom and running the entire length of the pen (Fig. 5). To help reduce intra-pen predation, fish over 140 mm were placed on one side of the partition, while resident fish under 140 mm were placed on the other side. Fish held in net-pens had access from the water surface to a depth of 4 m. Up to 100 individuals of each species were held in these pens. After 4 days, all fish from each of the three enclosure types were reexamined for external signs of GBD and other marks or injuries. Subsamples of up to 10 resident fish were examined more closely for gas bubbles in the lateral line, brachial arteries, and gill lamellae using a dissecting microscope with 20-power magnification. All resident fish mortalities were dissected and examined internally for signs of GBD except those in moderate to extreme states of decomposition.

Dissolved Gas Measurements

Tensionometers (D'Aoust et al. 1976) were used to measure TDGS at the time and place of sampling fish. Means and ranges of TDGS during 4-day holding periods were determined from dissolved gas data accessed from the Columbia River Operations Hydro-met System (CROHMS) data network of the U.S. Army Corps of Engineers. Additional TDGS data records were obtained every 4 hours at holding locations using tensionometers with data-logging capacity.

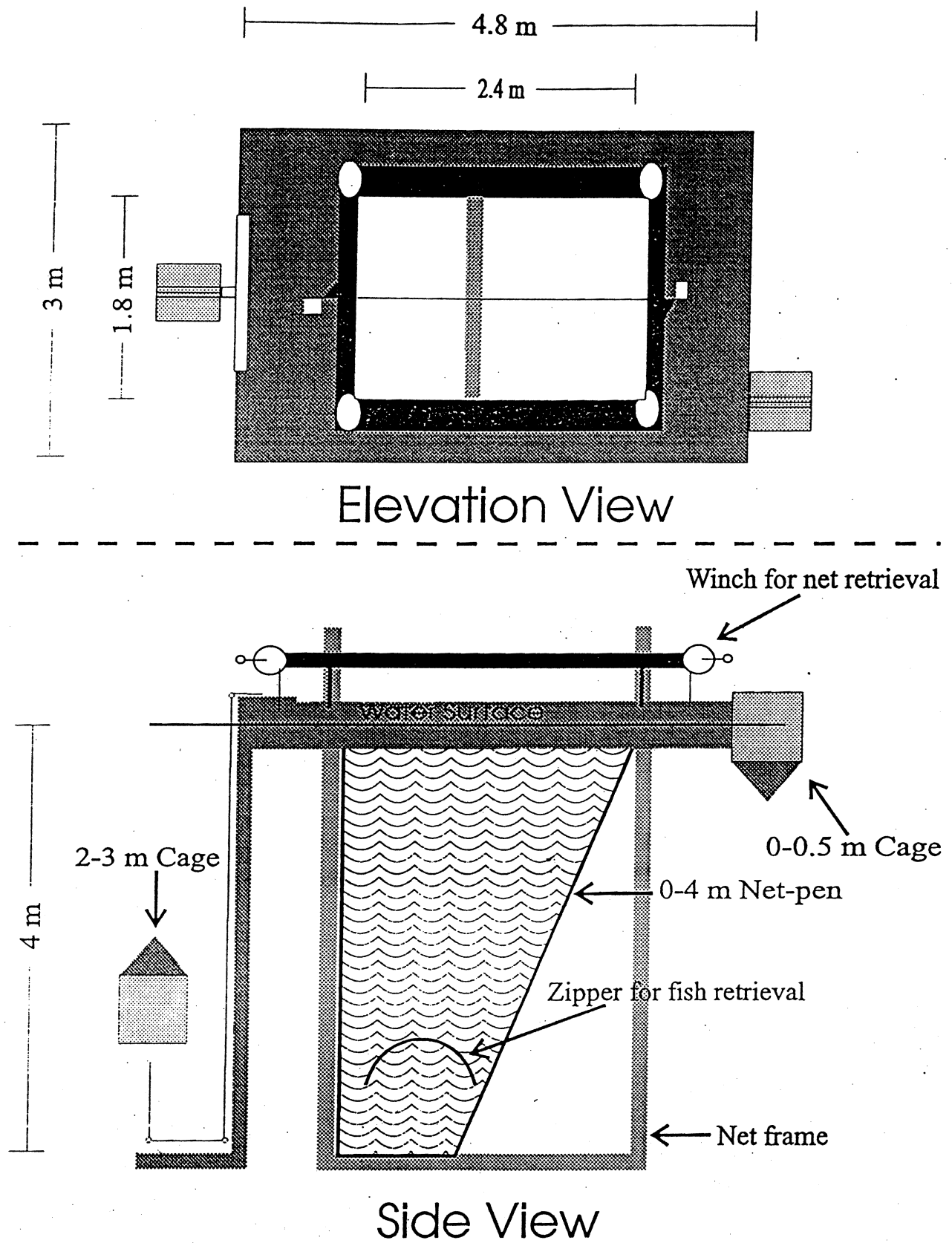


Figure 5. Net-pen, cages, and support barge used for resident fish holding experiments, 1996.

Gas Bubble Disease Effects Model

Our GBD effects model associates dissolved gas supersaturation (related to water flow and spill volumes) with the effects of GBD on resident fish in the Columbia River Basin. Using regression analysis, we examined correlations between exposure to ambient TDGS and external signs of GBD on sampled fish and then between percent external GBD signs and percent mortality in fish from the 0- to 4-m-deep net-pen experiments. Data necessary to predict external GBD signs (based on TDGS exposures) and mortality (based on external GBD signs) was obtained from numerous observations (13,642) of feral fish from river sampling and captive fish from net-pen experiments. These data included diverse dissolved gas levels observed from 1994 through 1996 in the three river reaches. Modeled effects are not representative of river areas where dissolved gas levels are 7% lower than measurements of in-river monitors (CROHMS Data) or of fish inhabiting water at depths greater than 3 m.

For analysis of GBD signs in feral fish, a minimum daily sample of at least 50 fish was established to eliminate possible anomalies due to small sample size. We used data only from resident fish sampled in areas where total dissolved gas saturation was within 7% of the CROHMS 24-hour mean midriver saturation level. This selection was intended to exclude GBD observations from fish inhabiting river locations where total dissolved gas saturations may have differed from those at monitoring stations (back-water ponds and channels).

We focused our sampling efforts for resident fish to depths between 0- and 3-m because the pressure compensation at the 3-m depth is approximately 30%. Therefore, a fish captured at 3-m would not experience effects from dissolved gas supersaturation until TDGS at the surface exceeded 130%. Except salmonids, all captured species that fell within these selection criteria

were included in the model. Fish fry were captured near the surface, and due to early life history stage were highly susceptible to GBD. For these reasons, fry were modeled separately.

Sampling and net-pen data were utilized for our model when collected from a location having continuity of dissolved gas measurements. To utilize sampling data we required a dissolved gas reading every 6 hours for 7 consecutive days prior to and during the sampling activity. To utilize net-pen data we required a total dissolved gas saturation reading every 6 hours during the course of the holding experiment. These criteria eliminated most of our 1994 sampling data because of inconsistent and inaccurate total dissolved gas saturation measurements. Data from samples taken downstream from Priest Rapids Dam were also eliminated due to lack of a monitoring instrument representative of sampling locations.

To help ensure that the mortalities were due to GBD, mortality data from the net-pens were only used from high saturation periods ($>120\%$) and when external GBD signs were present on surviving fish. For every surviving fish recovered from a qualifying holding experiment, we recorded the percent of surviving fish with external signs of GBD and the percent mortality for that experiment. To eliminate anomalies due to small sample sizes, experiments with fish samples smaller than five were not used when mortality data were being used for individual species models.

RESULTS

Signs of Gas Bubble Disease in Resident Fish

Downstream from Bonneville Dam

Individuals from 10 of the 25 taxa collected downstream from Bonneville Dam displayed external GBD signs. Included were 739 juvenile salmonids, 4,387 nonsalmonids, and 1,227 unidentified fry. Among all fish examined, 5.4% of salmonids, 2.1% of resident nonsalmonids, and 14.3% of fry exhibited signs of GBD (Tables 1 and 2).

From 30 May to 20 June, spill at Bonneville Dam caused TDGS to reach 139% downstream from the dam. This period corresponded to the greatest prevalence of GBD in sampled fish. Spill volumes¹ up to 259,600 ft³/sec and 64.5% of total river flow occurred (Appendix Fig. 1), and daily average TDGS remained above 125%. On 13 June, prevalence of GBD signs within individual daily fish samples reached 15.8% (Table 3)(Fig. 6). External signs of GBD among unidentified fish fry were observed on 8 of the 16 days during which they were sampled (Table 2). Signs of GBD in the lateral line and gill lamellae among fish sampled are summarized in Table 4.

Downstream from Priest Rapids Dam

Individuals from 9 of the 15 fish taxa collected downstream from Priest Rapids Dam along the Hanford Reach displayed external GBD signs. Included were 353 juvenile salmonids and 943 nonsalmonids. External signs of GBD were observed in 2.8% of salmonids and 6.5% of resident non-salmonids examined (Table 5).

¹By convention, English units were used for river flow volumes (1,000 ft³/s = 28.3 m³/s).

Table 1. Numbers sampled, size range, and prevalence of gas bubble disease (GBD) by species for fish collected downstream from Bonneville Dam, 1996.

Species	Scientific name	Sample (n)	Length range ^a (mm)	Prevalence of GBD ^b	
				(n)	(%)
Sucker	<i>Catostomus spp.</i>	1280	50-585	42	3.3
Peamouth	<i>Mylocheilus caurinus</i>	916	29-447	10	1.1
Stickleback	<i>Gasterosteus aculeatus</i>	657	25-109	3	0.5
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	626	45-225	25	4
Sculpin	<i>Cottus spp.</i>	596	28-420	20	3.4
Northern squawfish	<i>Ptychocheilus oregonensis</i>	443	39-603	15	3.4
Smallmouth bass	<i>Micropterus dolomieu</i>	117	37-439	0	
Carp	<i>Cyprinus carpio</i>	116	49-720	0	
Coho salmon	<i>Oncorhynchus kisutch</i>	105	113-175	14	13.3
Crappie	<i>Pomoxis spp.</i>	96	34-250	1	1
Redside shiner	<i>Richardsonius balteatus</i>	40	47-198	1	2.5
Yellow perch	<i>Perca flavescens</i>	26	96-241	0	
Chiselmouth	<i>Acrocheilus alutaceus</i>	21	115-352	0	
Killifish	<i>Fundulus spp.</i>	19	52-100	0	
Walleye	<i>Stizostedion vitreum</i>	12	58-710	0	
Bluegill	<i>Lepomis macrochirus</i>	10	95-131	0	
Whitefish	<i>Prosopium spp.</i>	10	88-444	0	
Largemouth bass	<i>Micropterus salmoides</i>	9	52-164	0	
Pumpkinseed	<i>Lepomis gibbosus</i>	8	95-130	0	
Steelhead	<i>Oncorhynchus mykiss</i>	8	165-210	1	12.5
Goldfish	<i>Carassius auratus</i>	5	76-252	0	
Bullhead	<i>Ictalurus spp.</i>	2	151	0	
American shad	<i>Alosa sapidissima</i>	1	172	0	
Dace	<i>Rhinichthys spp.</i>	1	90	0	
Starry flounder	<i>Platichthys stellatus</i>	1	115	0	
Unidentified fish		1	46	0	
<hr/>					
Total salmonids		739		40	5.4
Total nonsalmonids		4387		92	2.1

^a Total lengths were measured for all species except salmonids, for which fork lengths were measured.

^b External examination for signs of GBD using a 2.5- to 5.0-power headband magnifying lens.

Table 2. Total dissolved gas saturation (TDGS) at sampling location, number of fry collected, and prevalence of gas bubble disease (GBD) among fish fry sampled downstream from Bonneville Dam, 1996.

Date	Sample Location TDGS ^a	Fry (n) ^{b, c}	Prevalence of GBD ^d	
			(n)	(%)
6 Jun	123.9	5	5	100.0
11 Jun	122.7	5	4	80.0
12 Jun	92.7 ^e	31	0	0
	120.7	9	1	11.1
	124.7	49	34	69.4
13 Jun	119.9	6	5	83.3
	121.1	29	0	0
	125.4	52	36	69.2
18 Jun	118.8	85	0	0
	129.9	73	48	65.8
20 Jun	95.7	51	0	0
	123.0	64	34	53.1
26 Jun	120.9	53	8	15.1
27 Jun	112.9	57	0	0
3 Jul	114.1	102	1	1.0
	114.9	50	0	0
4 Jul	110.0	31	0	0
10 Jul	113.4	63	0	0
11 Jul	114.9	55	0	0
18 Jul	110.2	6	0	0
	112.4	61	0	0
24 Jul	118.1	98	0	0
	121.1	70	0	0
31 Jul	--	65	0	0
8 Aug	107.1	57	0	0
Total		1227	176	14.3

^a Total dissolved gas saturation at the sampling location.

^b Number of fry sampled at a particular location on specified day.

^c Range of total lengths; 11-24 mm.

^d Number and percentage of fry displaying signs of gas bubble disease.

^e Low saturation probably due to a reduction of water temperature during night hours at France Lake (shallow inlet adjacent to river channel).

Table 3. Total dissolved gas saturation (TDGS) at sampling sites, prevalence of external signs of gas bubble disease (GBD) by severity, and total prevalence of GBD among resident fish sampled downstream from Bonneville Dam, 1996.

Date	Sample (n)	Prevalence of GBD by severity					Total prevalence of GBD ^b (%)	% TDGS at sampling site(s)		
		Fins ^a				Body, eye, head (n)		Avg.	Range	
		Rank 1 (n)	Rank 2 (n)	Rank 3 (n)	Rank 4 (n)					
15 Mar	22	0	1	0	0	0	4.5	120	116.9-123.3	
16 Mar	49	0	0	0	0	0	0.0	118	116.4-120.6	
17 Mar	5	0	0	0	0	0	0.0	124	One measurement	
18 Mar	147	4	2	1	2	3	8.1	120	116.3-124.5	
19 Mar	134	3	1	2	0	5	8.2	118	117.5-118.3	
20 Mar	124	1	1	0	0	2	3.2	117	116.3-117.8	
21 Mar	109	0	0	0	1	3	3.7	119	118.4-119.3	
22 Mar	126	0	2	0	0	0	1.6	118	117.5-118.9	
23 Mar	18	1	0	0	0	0	5.6	117	One measurement	
24 Mar	135	0	0	0	0	0	0.0	112	One measurement	
8 Apr	27	0	0	0	0	0	0.0	120	One measurement	
19 Apr	52	2	0	0	0	0	3.8	117	One measurement	
24 Apr	11	0	0	0	0	0	0.0	119	One measurement	
25 Apr	113	1	0	0	1	0	1.8	119	113.3-122.2	
30 Apr	66	0	0	0	0	0	0.0	124	120.3-127.5	
2 May	21	0	0	0	1	0	4.8	116	One measurement	
6 May	101	1	0	1	0	0	2.0	118	117.3-118.9	
10 May	20	0	0	0	0	0	0.0	110	One measurement	
13 May	117	2	0	0	0	0	1.7	114	112.7-114.7	
16 May	17	0	0	0	0	0	0.0	122	One measurement	
20 May	120	1	0	0	0	1	1.6	117	112.0-121.8	
23 May	28	0	0	0	0	0	0.0	119	One measurement	
28 May	114	5	0	0	0	0	4.4	121	118.2-123.8	
30 May	25	0	0	0	0	0	0.0	125	One measurement	
3 Jun	133	15	1	0	0	2	13.5	126	127.0-125.6	
6 Jun	37	1	0	0	0	0	2.7	124	One measurement	
10 Jun	162	10	1	2	0	1	8.6	126	124.2-128.1	
11 Jun	11	0	0	0	0	0	0.0	125	122.7-126.6	
13 Jun	38	4	1	0	1	0	15.8	121	One measurement	
17 Jun	160	5	1	0	0	0	3.8	122	117.8-123.7	
19 Jun	29	1	0	0	0	0	3.4	127	One measurement	

Table 3. Continued

Date	Sample (n)	Prevalence of GBD by severity				Body, eye, head (n)	Prevalence of GBD ^b (%)	% TDGS at sampling site(s)			
		Fins ^a						Avg.	Range		
		Rank 1 (n)	Rank 2 (n)	Rank 3 (n)	Rank 4 (n)						
24 Jun	110	0	0	0	0	0	0.0	119	111.0-124.1		
25 Jun	30	1	0	0	0	0	3.3	117	One measurement		
26 Jun	73	3	0	0	0	1	5.5	124	120.9-130.5		
27 Jun	134	2	0	0	0	2	3.0	119	116.3-121.1		
1 Jul	124	0	0	0	0	0	0.0	119	118.3-119.6		
2 Jul	43	1	0	0	0	0	2.3	117	One measurement		
3 Jul	96	0	0	0	0	0	0.0	114	113.3-114.8		
4 Jul	155	0	0	0	0	0	0.0	110	109.1-110.0		
8 Jul	123	0	0	0	0	0	0.0	119	118.6-119.1		
9 Jul	49	0	0	0	0	0	0.0	114	113.4-115.4		
11 Jul	198	0	0	0	0	0	0.0	109	107.6-110.3		
15 Jul	167	1	0	0	0	0	0.6	119	118.3-118.8		
16 Jul	74	0	0	0	0	0	0.0	113	One measurement		
18 Jul	130	0	0	0	0	0	0.0	110	109.2-110.8		
22 Jul	166	0	0	0	0	0	0.0	116	115.3-116.7		
23 Jul	37	0	0	0	0	0	0.0	117	One measurement		
25 Jul	166	0	0	0	0	2	1.2	117	116.4-117.5		
29 Jul	243	1	2	0	0	5	3.3	112	108.0-115.7		
30 Jul	134	3	0	0	0	3	4.4	111	One measurement		
31 Jul	266	0	0	0	0	0	0.0	109	108.2-109.2		
5 Aug	136	1	0	0	0	1	1.4	109	106.5-111.0		
7 Aug	156	0	0	0	0	0	0.0	111	109.3-111.5		
12 Aug	50	0	0	0	0	0	0.0	108	One measurement		

^a Rank (determined from percent of total fin area affected with emphysema): 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = > 50%.

^b Not including fish with GBD in lateral line and/or gill.

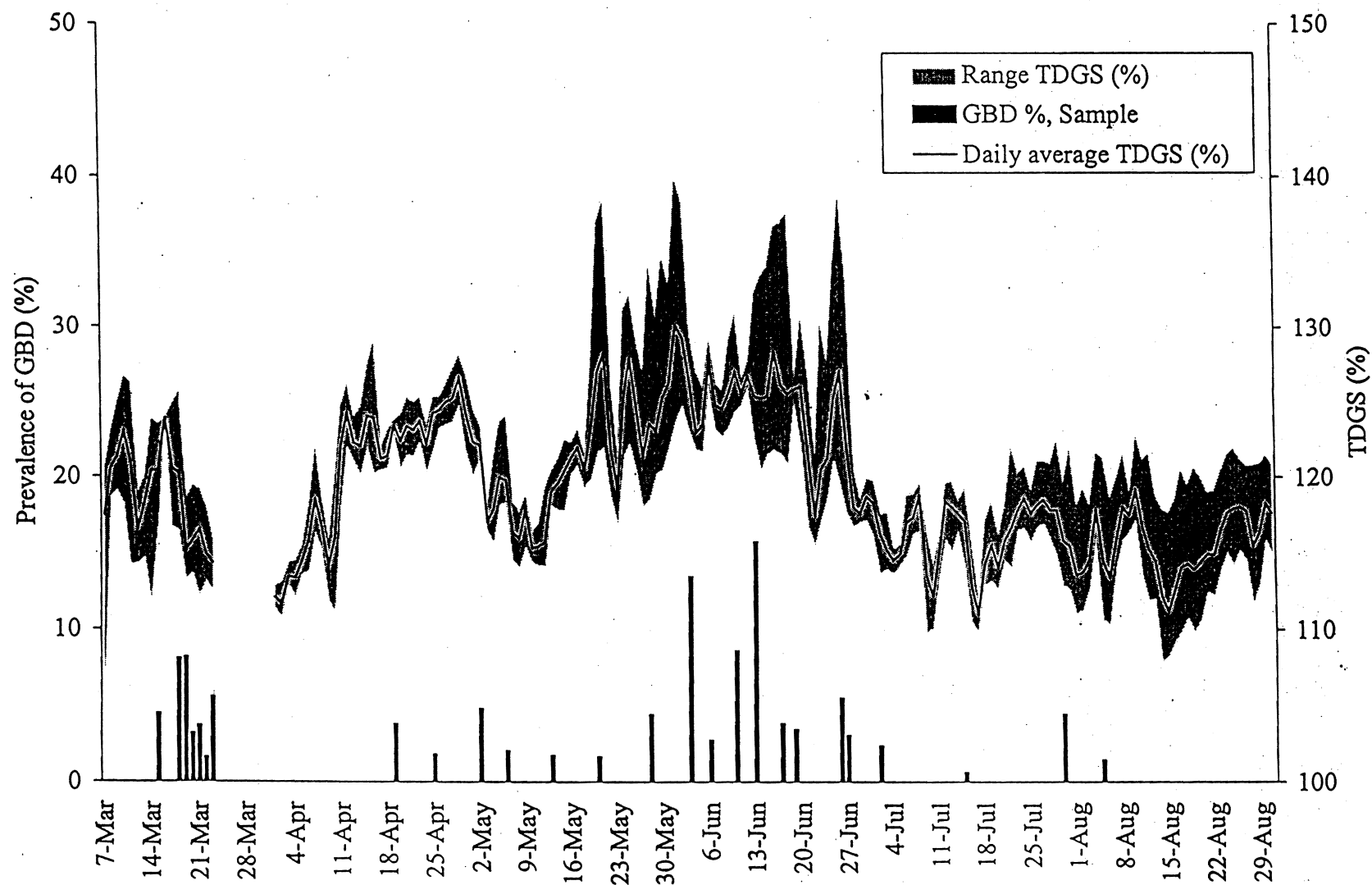


Figure 6. Prevalence of GBD in resident fish collected downstream from Bonneville Dam compared with daily average and range of total dissolved gas saturation (TDGS) (COE, Skamania).

Table 4. Total dissolved gas saturation (TDGS) at sampling sites and prevalence of gas bubble disease (GBD) signs in the lateral line and gill lamellae among resident fish, 1996.

Downstream from Bonneville Dam						Downstream from Priest Rapids Dam					
Date	Lateral line ^a	Gill lamellae ^b	% TDGS at sampling site(s)			Date	Lateral line ^a	Gill lamellae ^b	% TDGS at sampling site(s)		
			Avg.	Min.	Max.				Avg.	Min.	Max.
15 Mar	1/8	1/8	120	116.9	123.3	18 Apr	1/10	0/0	121	119.3	124.3
16 Mar	1/6	0/6	118	116.4	120.6	1 May	1/10	0/10	130	One measurement	
17 Mar	1/5	0/5	124	One measurement		2 May	0/10	0/10	124	One measurement	
18 Mar	3/6	0/6	120	116.3	124.5	7 May	8/10	0/10	120	118.3	121.2
19 Mar	2/2	0/2	118	117.5	118.3	16 May	2/5	3/5	120	One measurement	
20 Mar	6/7	0/7	117	116.3	117.8	22 May	4/5	1/5	119	One measurement	
21 Mar	3/15	0/15	119	118.4	119.3	23 May	6/10	5/10	115	One measurement	
22 Mar	1/7	0/7	118	117.5	118.9	29 May	2/9	1/9	128	One measurement	
23 Mar	2/7	0/7	117	One measurement		5 Jun	0/1	1/1	122	120.6	123.3
24 Mar	3/7	0/7	112	One measurement		12 Jun	1/10	1/10	121	120.7	121.2
8 Apr	2/10	0/0	120	One measurement		20 Jun	0/5	1/5	125	One measurement	
2 May	2/10	0/10	116	One measurement		3 Jul	0/3	0/3	124	One measurement	
10 May	3/9	0/9	110	One measurement		10 Jul	1/11	1/11	118	116.9	118.7
16 May	4/10	0/10	122	One measurement		17 Jul	1/10	2/10	121	120.4	122.3
23 May	0/10	0/10	119	One measurement		8 Aug	0/5	3/5	114	One measurement	
30 May	3/10	0/10	125	One measurement							
3 Jun	1/1	0/1	126	127.0	125.6						
6 Jun	1/10	1/10	124	One measurement							
11 Jun	2/9	0/9	125	122.7	126.6						
19 Jun	2/10	0/10	127	One measurement							
25 Jun	1/10	0/10	117	One measurement							
2 Jul	3/10	0/10	117	One measurement							
9 Jul	0/10	0/10	114	113.4	115.4						
16 Jul	0/10	0/10	113	One measurement							
23 Jul	0/10	0/10	117	One measurement							
30 Jul	0/13	0/13	111	One measurement							

Upstream from Priest Rapids Dam						Downstream from Ice Harbor Dam					
Date	Lateral line ^a	Gill lamellae ^b	% TDGS at sampling site(s)			Date	Lateral line ^a	Gill lamellae ^b	% TDGS at sampling site(s)		
			Avg.	Min.	Max.				Avg.	Min.	Max.
17 Apr	4/10	0/0	128	128.0	128.0	29 Apr	1/6	1/6	129	122.3	135.3
30 Apr	1/6	0/6	115	One measurement		6 May	8/11	1/11	118	One measurement	
8 May	9/10	2/10	126	One measurement		14 May	5/6	3/6	123	One measurement	
13 May	8/10	4/10	123	One measurement		21 May	6/10	2/10	132	125.2	137.8
20 May	8/11	5/11	131	One measurement		28 May	7/10	5/10	130	One measurement	
27 May	1/10	0/10	124	One measurement		30 May	3/7	0/7	135	131.1	137.9
3 Jun	6/10	1/10	133	One measurement		13 Jun	2/10	0/10	123	One measurement	
10 Jun	2/10	4/10	130	One measurement		19 Jun	5/10	0/10	120	117.1	122.0
17 Jun	2/10	0/10	109	One measurement		25 Jun	1/8	0/8	114	113.9	114.0
24 Jun	3/11	2/11	121	119.0	122.4	9 Jul	4/5	0/5	116	110.0	121.1
1 Jul	2/9	1/10	103	One measurement		11 Jul	1/4	1/4	119	118.2	120.2
8 Jul	2/10	0/10	119	One measurement		18 Jul	1/6	4/6	103	One measurement	
15 Jul	1/8	1/8	134	One measurement		30 Jul	2/5	1/5	100	One measurement	
29 Jul	0/6	2/6	95	One measurement		13 Aug	1/2	0/2	105	One measurement	

^a Number of fish with GBD signs in the lateral line/number examined.^b Number of fish with GBD signs in gill lamellae/number examined.

Table 5. Numbers sampled, size range, and prevalence of gas bubble disease (GBD) by species for fish collected downstream from Priest Rapids Dam, 1996.

Species	Scientific name	Sample (n)	Length range ^a (mm)	Prevalence of GBD ^b	
				(n)	(%)
Sucker	<i>Catostomus spp.</i>	371	52-760	49	13.2
Northern squawfish	<i>Ptychocheilus oregonensis</i>	284	60-493	6	2.1
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	231	36-195	7	3.0
Steelhead	<i>Oncorhynchus mykiss</i>	95	37-254	1	1.1
Peamouth	<i>Mylocheilus caurinus</i>	91	40-480	1	1.1
Redside shiner	<i>Richardsonius balteatus</i>	70	45-151	1	1.4
Chiselmouth	<i>Acrocheilus alutaceus</i>	66	61-290	3	4.5
Sockeye salmon	<i>Oncorhynchus nerka</i>	27	147-232	2	7.4
Mountain whitefish	<i>Prosopium williamsoni</i>	14	166-440	0	0.0
Smallmouth bass	<i>Micropterus dolomieu</i>	13	74-250	1	7.7
Carp	<i>Cyprinus carpio</i>	11	84-670	0	
Sculpin	<i>Cottus spp.</i>	10	58-203	0	
Yellow perch	<i>Perca flavescens</i>	10	45-181	0	
Stickleback	<i>Gasterosteus aculeatus</i>	2	59	0	
Bullhead	<i>Ictalurus spp.</i>	1	172	0	
<hr/>					
Total salmonids		353		10	2.8
Total nonsalmonids		943		61	6.5

^a Total lengths were measured for all species except salmonids, for which fork lengths were measured.

From 24 May to 21 June, spill at Priest Rapids Dam caused TDGS to reach 130% downstream from the dam. Spill volumes up to 132,500 ft³/sec and 50.8% of total river flow occurred (Appendix Fig. 2), and daily average TDGS remained near 125%. Prevalence of external GBD signs within individual daily samples never exceeded 15% (Table 6)(Fig. 7). Signs of GBD in the lateral line and gill lamellae are summarized in Table 4.

Priest Rapids Reservoir

Individuals from 11 of the 20 taxa collected in Priest Rapids Reservoir displayed external signs of GBD. Included were 60 juvenile salmonids and 2,220 resident nonsalmonids. Among all fish examined, no salmonids and 7.3% of resident nonsalmonids exhibited external signs of GBD (Table 7)

From 27 May to 24 June, spill at Wanapum Dam caused TDGS to reach 136% in Priest Rapids Reservoir. This period corresponded to the greatest prevalence of external GBD signs in sampled fish. Spill volumes up to 131,600 ft³/sec and 50.1% of total river flow occurred (Appendix Fig. 3), and daily average TDGS remained above 125%. Prevalence of GBD signs within individual daily fish samples reached 23.1% on 27 May and 16.7% on 3 June (Table 8) (Fig. 8). Signs of GBD in the lateral line and gill lamellae among fish sampled are summarized in Table 4.

Table 6. Total dissolved gas saturation (TDGS) at sampling sites, prevalence of external signs of gas bubble disease (GBD) by severity, and total prevalence of GBD among resident fish sampled downstream from Priest Rapids Dam, 1996.

Date	Sample (n)	Prevalence of GBD by severity				Body, eye, head (n)	Total prevalence of GBD ^b (%)	% TDGS at sampling sites			
		Fins ^a						Avg.	Range		
		Rank	Rank	Rank	Rank						
		1	2	3	4						
		(n)	(n)	(n)	(n)						
10 Apr	8	0	0	0	0	0	0.0	118	117.9-117.9		
18 Apr	110	8	1	2	2	0	11.8	121	119.3-124.3		
1 May	64	3	1	0	0	0	6.3	130	One measurement		
2 May	67	3	0	0	0	0	4.5	124	One measurement		
7 May	53	1	1	0	0	0	3.8	120	118.3-121.2		
15 May	8	0	0	0	0	0	0.0	115	One measurement		
16 May	45	0	0	0	0	0	0.0	120	One measurement		
22 May	69	2	2	1	0	0	7.2	119	One measurement		
23 May	73	6	3	0	1	0	13.7	115	One measurement		
29 May	116	3	0	1	2	0	5.2	128	One measurement		
5 Jun	138	7	2	3	1	1	10.1	122	120.6-123.3		
12 Jun	61	0	0	0	0	0	0.0	121	120.7-121.2		
20 Jun	63	0	0	0	0	2	3.2	125	One measurement		
3 Jul	10	1	0	0	0	0	10.0	124	One measurement		
10 Jul	89	0	0	0	0	0	0.0	118	116.9-118.7		
17 Jul	114	2	0	0	1	1	3.5	121	120.4-122.3		
25 Jul	60	3	3	0	0	0	10.0	122	121.2-121.8		
31 Jul	54	0	0	0	0	0	0.0	117	120.4-122.3		
8 Aug	57	0	0	0	0	0	0.0	114	One measurement		

^a Rank (determined from percent of total fin area affected with emphysema): 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = >50%.

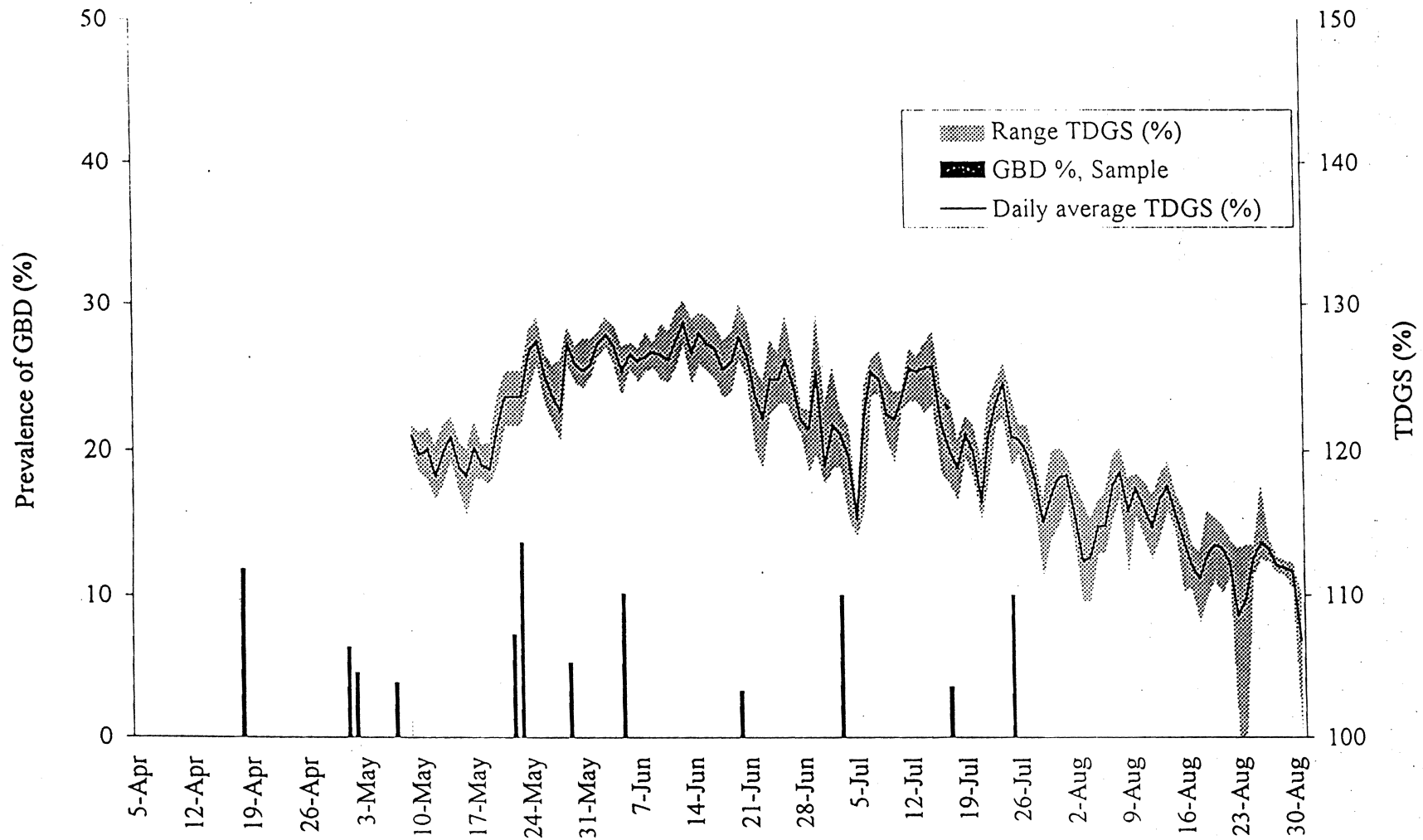


Figure 7. Prevalence of GBD in resident fish collected downstream from Priest Rapids Dam compared with daily average and range of total dissolved gas saturation (TDGS) (COE, Priest Rapids Dam Tailrace).

Table 7. Numbers sampled, size range, and prevalence of gas bubble disease (GBD) by species for fish collected in Priest Rapids Reservoir, 1996.

Species	Scientific name	Sample (n)	Length range ^a (mm)	Prevalence of GBD ^b	
				(n)	(%)
Northern squawfish	<i>Ptychocheilus oregonensis</i>	651	10-545	13	2.0
Chiselmouth	<i>Acrocheilus alutaceus</i>	510	41-230	35	6.9
Sucker	<i>Catostomus spp.</i>	290	60-595	77	26.6
Redside shiner	<i>Richardsonius balteatus</i>	248	39-160	4	1.6
Pumpkinseed	<i>Lepomis gibbosus</i>	175	50-187	9	5.1
Peamouth	<i>Mylocheilus caurinus</i>	99	56-295	2	2.0
Sculpin	<i>Cottus spp.</i>	77	66-205	12	15.6
Smallmouth bass	<i>Micropterus dolomieu</i>	70	41-400	3	4.3
Yellow perch	<i>Perca flavescens</i>	50	43-220	0	
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	35	42-102	0	
Steelhead trout	<i>Oncorhynchus mykiss</i>	25	51-240	0	
Stickleback	<i>Gasterosteus aculeatus</i>	17	31-67	1	5.9
Sandroller	<i>Percopsis transmontana</i>	14	83-111	4	28.6
Bluegill	<i>Lepomis macrochirus</i>	6	32-113	1	16.7
Carp	<i>Cyprinus carpio</i>	5	60-330	0	
Largemouth bass	<i>Micropterus salmoides</i>	4	75-131	0	
American shad	<i>Alosa sapidissima</i>	1	159	0	
Lamprey	<i>Lampertra ayresi</i>	1	210	0	
Crappie	<i>Pomoxis spp.</i>	1	97	0	
Walleye	<i>Stizostedion vitreum</i>	1	272	0	
<hr/>					
Total salmonids		60		0	0.0
Total nonsalmonids		2,220		161	7.3

^a Total lengths were measured for all species except salmonids for which fork lengths were measured.

^b External examination for signs of GBD using a 2.5- to 5.0-power headband magnifying lens.

Table 8. Total dissolved gas saturation (TDGS) at sampling sites, prevalence of external signs of gas bubble disease (GBD) by severity, and total prevalence of GBD among resident fish collected in Priest Rapids Reservoir, 1996.

Date	Sample (n)	Prevalence of GBD by severity				Body, eye, head (n)	Prevalence of GBD ^b (%)	% TDG at sampling sites			
		Fins ^a						Avg.	Range		
		Rank 1 (n)	Rank 2 (n)	Rank 3 (n)	Rank 4 (n)						
9 Apr	48	0	0	0	0	0	0.0	122	122.0-122.0		
17 Apr	124	1	0	0	0	1	1.6	128	128.0-128.0		
30 Apr	196	12	3	1	0	3	9.7	115	One measurement		
8 May	200	3	0	0	0	3	3.0	126	One measurement		
13 May	123	3	2	1	3	0	7.3	123	One measurement		
20 May	187	6	3	0	2	1	6.4	131	One measurement		
24 May	76	2	2	0	1	0	6.6	135	One measurement		
27 May	139	17	9	2	1	3	23.1	124	One measurement		
3 Jun	138	15	4	0	0	4	16.7	133	One measurement		
10 Jun	176	10	0	0	1	10	12.0	130	One measurement		
17 Jun	118	2	0	0	0	0	1.7	109	One measurement		
24 Jun	71	1	1	1	3	1	9.9	121	119.0-122.4		
1 Jul	79	3	1	0	0	1	6.4	103	One measurement		
8 Jul	104	0	0	0	0	0	0.0	119	One measurement		
15 Jul	82	6	2	2	0	3	15.9	134	One measurement		
22 Jul	68	0	0	0	0	0	0.0	127	One measurement		
29 Jul	75	0	0	0	0	0	0.0	95	One measurement		
5 Aug	38	0	0	0	0	0	0.0	117	One measurement		
12 Aug	73	1	0	0	0	0	1.4	108	One measurement		

^a Rank (determined from percent of total fin area affected with emphysema): 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = >50%.

^b Not including fish with GBD in lateral line and/or gill.

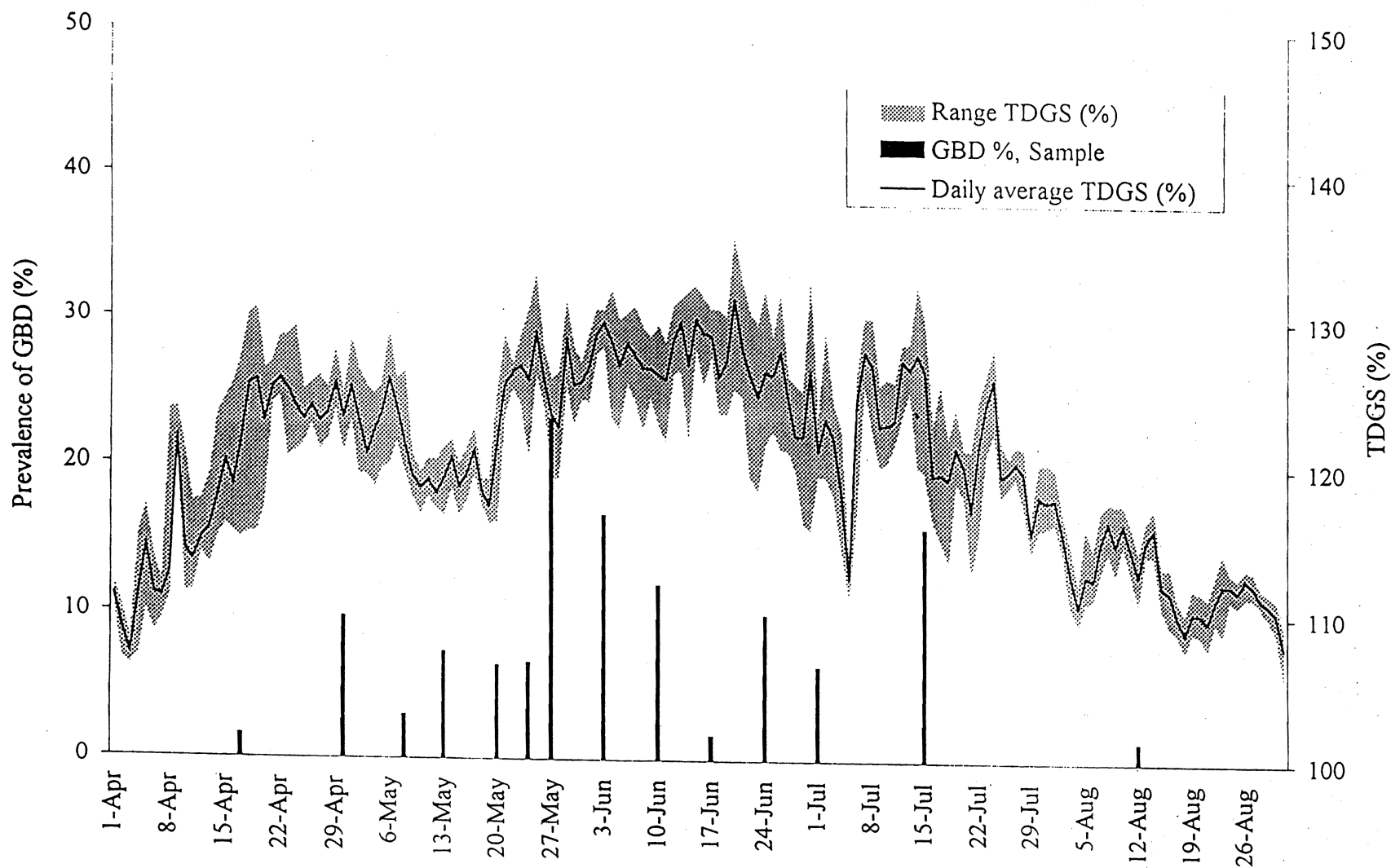


Figure 8. Prevalence of GBD in resident fish collected from the Columbia River in Priest Rapids Reservoir compared with daily average and range of total dissolved gas saturation (TDGS) (COE, Priest Rapids Dam Forebay)

Downstream from Ice Harbor Dam

Individuals from 15 of the 17 taxa collected downstream from Ice Harbor Dam displayed external signs of GBD. No salmonids were included, but of the 2,377 nonsalmonids examined 1.2% exhibited external signs of GBD (Table 9).

From 1 April to 30 April, and 15 May to 24 June, spill at Ice Harbor Dam, along with turbine outages, caused TDGS to reach 142% downstream from the dam. This period corresponded to the greatest prevalence of external GBD signs in sampled fish. Spill volumes up to 116,900 ft³/sec and 60.9% of total river flow occurred (Appendix Fig. 4), and daily average TDGS generally remained above 130%. Prevalence of GBD signs within individual daily fish samples was greater than 30% on 29 April, 30 May, 6 June, 11 June, and 20 June (Table 10)(Fig. 9). Signs of GBD in the lateral line and gill lamellae among fish sampled are summarized in Table 4.

Just outside the mouth of the Snake River lie several small islands in a shallow-water area that is thought to be a rearing area for fall chinook salmon. This area presents the possibility of abnormally high water temperature due to solar heating, and therefore the capacity for increased dissolved gas supersaturation. To evaluate the effects of TDGS on juvenile chinook salmon in this area, we observed several small samples between 19 June and 16 July, when TDGS ranged from 114 to 122%. However, our examination of 22 juvenile chinook salmon revealed no signs of GBD, suggesting that impacts to salmon were minimal.

Table 9. Numbers sampled, size range, and prevalence of gas bubble disease (GBD) by species for fish collected downstream from Ice Harbor Dam, 1996.

Species	Scientific name	Sample (n)	Length range ^a (mm)	Prevalence of GBD ^b	
				(n)	(%)
Sucker	<i>Catostomus spp.</i>	422	63-595	91	21.6
Smallmouth bass	<i>Micropterus dolomieu</i>	392	44-535	47	12.0
Sculpin	<i>Cottus spp.</i>	304	50-180	40	13.2
Largemouth bass	<i>Micropterus salmoides</i>	202	37-526	5	2.5
Bluegill	<i>Lepomis macrochirus</i>	199	35-177	4	2.0
Northern squawfish	<i>Ptychocheilus oregonensis</i>	195	61-500	24	12.3
Peamouth	<i>Mylocheilus caurinus</i>	184	70-346	14	7.6
Yellow perch	<i>Perca flavescens</i>	163	50-436	20	12.3
Pumpkinseed	<i>Lepomis gibbosus</i>	75	56-187	6	8.0
Chiselmouth	<i>Acrocheilus alutaceus</i>	71	77-306	5	7.0
Carp	<i>Cyprinus carpio</i>	46	63-730	5	10.9
Crappie	<i>Pomoxis spp.</i>	38	40-276	1	2.6
Bullhead	<i>Ictalurus spp.</i>	33	60-368	2	6.1
Redside shiner	<i>Richardsonius balteatus</i>	31	53-181	2	6.5
Whitefish	<i>Prosopium spp.</i>	16	100-340	1	6.3
American shad	<i>Alosa sapidissima</i>	4	412-440	0	
Channel catfish	<i>Ictalurus punctatus</i>	1	195	0	
Unidentified fish		1	44	0	
Total salmonids		0		0	
Total nonsalmonids		2,377		267	11.2

^a Total lengths were measured for all species except salmonids for which fork lengths were measured.

^b External examination for signs of GBD using a 2.5- to 5.0-power headband magnifying lens.

Table 10. Total dissolved gas saturation (TDGS) at sampling sites, prevalence of external signs of gas bubble disease (GBD) by severity, and total prevalence of GBD among resident fish collected downstream from Ice Harbor Dam, 1996.

Date	Sample (n)	Prevalence of GBD by severity				Body, eye, head (n)	Prevalence of GBD ^b (%)	% TDGS			
		Fins ^a						at sampling site/s			
		Rank	Rank	Rank	Rank			Avg.	Range		
		1 (n)	2 (n)	3 (n)	4 (n)						
16 Apr	55	5	6	3	0	1	27.3	126	One measurement		
24 Apr	31	4	0	0	0	1	16.1	118	One measurement		
29 Apr	90	20	8	0	0	6	37.8	129	122.3-135.3		
6 May	108	3	1	0	0	3	6.5	118	One measurement		
9 May	108	2	1	0	0	5	7.7	117	113.4-120.6		
14 May	62	0	1	0	0	2	4.8	123	One measurement		
21 May	118	12	5	4	0	2	19.5	132	125.2-137.8		
28 May	154	15	6	2	0	5	18.1	130	One measurement		
30 May	93	4	7	1	4	15	33.3	135	131.1-137.9		
4 Jun	78	6	0	2	1	10	24.3	129	124.3-136.6		
6 Jun	51	6	4	2	1	5	35.3	125	113.9-136.0		
11 Jun	31	6	3	1	0	1	35.5	116	106.9-125.2		
13 Jun	189	7	1	0	0	1	4.7	123	One measurement		
19 Jun	78	2	0	0	1	0	3.8	120	117.1-122.0		
20 Jun	34	2	0	1	0	9	35.3	120	One measurement		
25 Jun	70	1	1	0	0	6	11.5	114	113.9-114.0		
2 Jul	63	2	0	0	0	1	4.8	121	One measurement		
9 Jul	93	1	0	0	0	1	2.2	116	110.0-121.1		
11 Jul	57	2	0	0	0	0	3.5	119	118.2-120.2		
16 Jul	19	0	0	0	0	0	0.0	115	One measurement		
18 Jul	71	2	0	0	0	0	2.8	103	One measurement		
24 Jul	79	0	0	0	0	0	0.0	103	101.1-104.9		
30 Jul	88	3	0	0	0	0	3.4	100	One measurement		
1 Aug	28	1	0	0	0	0	3.6	124	One measurement		
6 Aug	94	0	0	0	0	0	0.0	105	102.7-106.5		
7 Aug	48	0	0	0	0	0	0.0	102	One measurement		
13 Aug	62	1	0	0	0	0	1.6	105	One measurement		
15 Aug	166	0	0	0	0	1	0.0	107	99.3-113.8		

^a Rank (determined from percent of total fin area affected with emphysema): 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = >50%.

^b Not including fish with GBD in lateral line and/or gill.

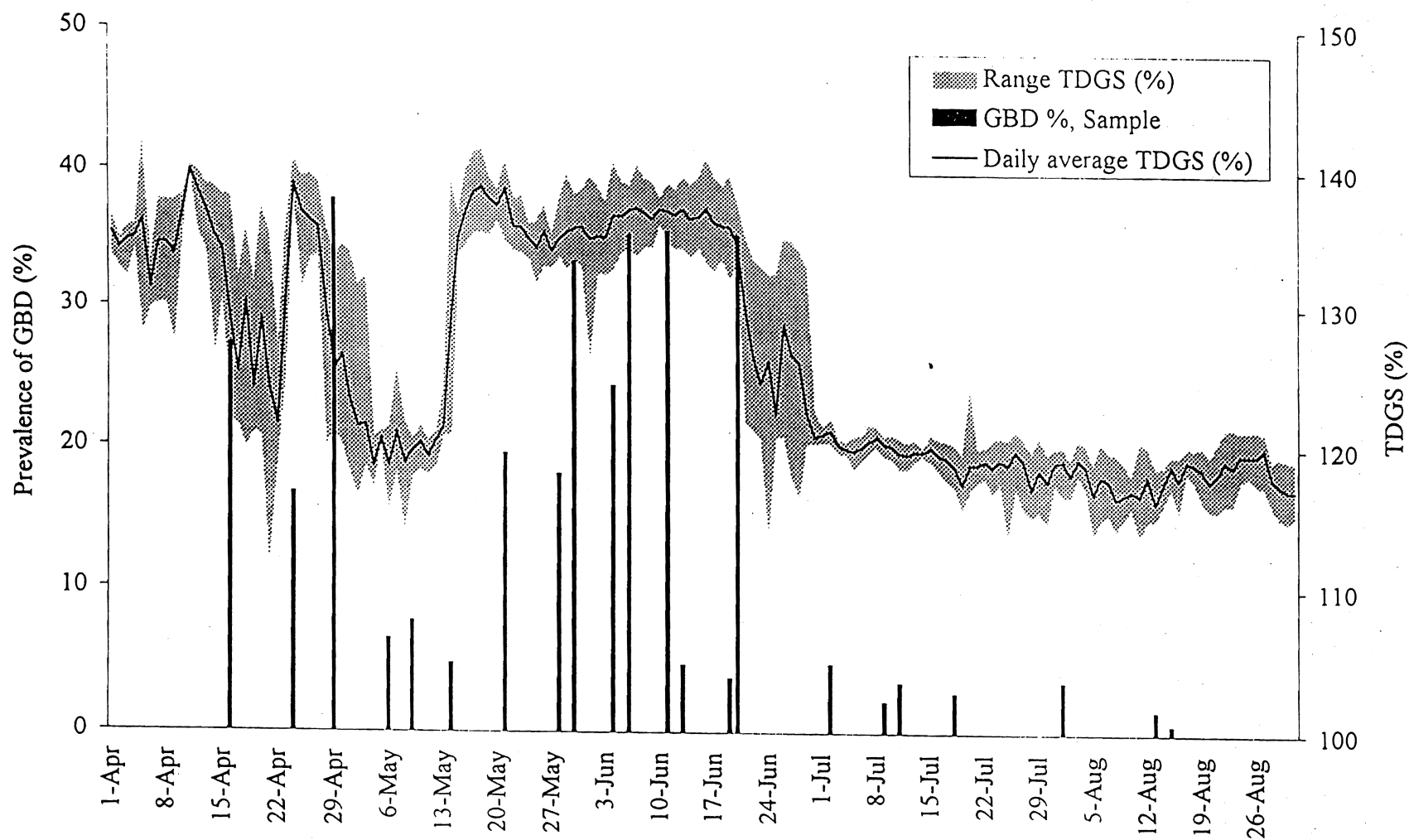


Figure 9. Prevalence of GBD in resident fish collected from the Snake River in Ice Harbor Dam tailrace compared with daily average and range of total dissolved gas saturation (TDGS) (COE, Ice Harbor Dam tailrace).

Gas Bubble Disease in Captive Fish Groups

Downstream from Bonneville Dam

Results of net-pen holding experiments conducted with resident fish downstream from Bonneville Dam are summarized in Table 11. External signs of GBD were observed among surviving resident fish held in the 0- to 0.5-m pen in all 13 4-day holding periods (prevalence range 4.3-100%) from 17 May through 9 August, when TDGS ranged from 110 to 140%. Fish held in the 0- to 4-m pen showed external signs of GBD on 7 of the 13 holding periods (prevalence range 0-58.4%); prevalence increased during every 4-day holding period conducted from 17 May to 24 June (Fig. 10). External signs of GBD among resident fish held in the 2- to 3-m pen were observed in only 3 of the 13 holding periods (prevalence range 0-8.3%).

Prevalence of GBD signs in the lateral line among surviving fish groups removed from the 0- to 0.5-m pen was not consistently higher than among fish groups removed from the 0- to 4-m or 2- to 3-m pens during the same 4-day holding periods. Prevalence of GBD signs in the lateral line among fish removed from the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 100.0%, 0 to 66.7%, and 0 to 66.7%, respectively.

Signs of GBD in the gills were observed among fish groups removed from the 0- to 0.5-m pen on 6 of the 13 4-day holding periods (prevalence range 16.7-50%). No GBD signs in gills were observed among fish removed from either the 0- to 4-m or 2- to 3-m pens.

In holding experiments where prevalence of GBD signs among surviving fish increased, that is, when impacts from GBD affected captive fish, mortality among groups held in 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 83%, 0 to 4%, and remained at 0%, respectively (Table 11).

Table 11. Gas bubble disease (GBD), mortality, and total dissolved gas saturation (TDGS) during net-pen experiments holding resident fish downstream from Bonneville Dam, 1996.

Date/ Conditions	Introduction ^a		Survivors Examined ^b						Mortalities Examined									
	external ^c GBD		external ^c GBD		LL ^d GBD		gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD		gill ^e GBD		
	(n)	(%)	(n)	(%)	(n) ^g	(%)	(n) ^g	(%)	(n)	(%)		(n) ^g	(%)	(n) ^g	(%)	(n) ^g	(%)	
May 13-17																		
TDGS ^k 120% (118-123%)																		
surface (0-0.5 m)	25	0	22	86.4	6	33.3	6	16.7	1	4.3	0	1	0	0	--	0	--	
0-4 m	52	0	50	8	4	25	3	0	2	3.8	0	2	50	2	0	0	--	
deep (2-3 m)	21	0	17	5.9	3	33.3	3	0	0	0	0	--	--	--	--	--	--	
May 20-24																		
TDGS 124% (117-138%)																		
surface (0-0.5 m)	12	0	5	100	4	100	4	0	7	58.3	0	7	100	7	85.7	4	25	
0-4 m	78	0	73	20.5	3	0	3	0	0	0	0	--	--	--	--	--	--	
deep (2-3 m)	12	8.3	12	8.3	3	33.3	3	0	0	0	0	--	--	--	--	--	--	
May 28-Jun 1																		
TDGS 126% (119-140%)																		
surface (0-0.5 m)	11	0	7	100	4	75	4	50	4	36.4	0	4	75	4	100	4	75	
0-4 m	79	5.1	77	58.4	3	66.7	3	0	1	1.3	1	--	--	--	--	--	--	
deep (2-3 m)	8	0	8	0	3	66.7	3	0	0	0	0	--	--	--	--	--	--	
Jun 3-7																		
TDGS 124% (122-130%)																		
surface (0-0.5 m)	19	5.3	10	100	4	100	4	25	9	47.4	0	9	100	8	100	5	60	
0-4 m	71	19.7	69	27.5	3	33.3	3	0	1	1.4	0	1	100	1	100	1	0	
deep (2-3 m)	17	0	17	0	3	0	3	0	0	0	0	--	--	--	--	--	--	
Jun 10-14																		
TDGS 127% (123-133%)																		
surface (0-0.5 m)	14	0	11	100	4	50	4	50	3	21.4	0	3	100	3	66.7	3	100	
0-4 m	95	13.7	90	40	3	0	3	0	2	2.2	0	2	0	2	50	2	0	
deep (2-3 m)	13	0	13	7.7	3	33.3	3	0	0	0	0	--	--	--	--	--	--	
Jun 17-21																		
TDGS 126% (121-138%)																		
surface (0-0.5 m)	16	0	15	86.7	4	75	4	25	1	6.3	0	1	100	1	100	1	100	
0-4 m	95	7.4	93	12.9	5	40	5	0	1	1.1	0	1	0	1	100	1	100	
deep (2-3 m)	11	0	11	0	3	33.3	3	0	0	0	--	--	--	--	--	--	--	
Jun 24-28																		
TDGS 123% (117-139%)																		
surface (0-0.5 m)	24	0	4	25	4	25	4	25	19	82.6	0	19	78.9	19	52.6	13	53.8	
0-4 m	60	0	53	13.2	5	20	5	0	2	3.6	0	2	50	1	0	1	0	
deep (2-3 m)	16	0	11	0	3	0	3	0	0	0	--	--	--	--	--	--	--	

Table 11. Continued.

Date/ Conditions	Introduction ^a		Survivors Examined ^b								Mortalities Examined							
	external ^c GBD		external ^c GBD		I.L. ^d GBD		gill ^e GBD		Mortality		Decom. ^f (n)	external ^c GBD		I.L. ^d GBD		gill ^e GBD		
	(n)	(%)	(n)	(%)	(n) ^g	(%)	(n) ^g	(%)	(n)	(%)		(n) ^g	(%)	(n) ^g	(%)	(n) ^g	(%)	
Jul 1-5	TDGS 117% (114-120%)																	
surface (0-0.5 m)	20	0	18	33.3	6	0	6	0	2	10	0	2	50	1	0	1	0	
0-4 m	70	0	65	0	3	33.3	3	0	1	1.5	0	1	0	1	0	0	--	
deep (2-3 m)	15	0	12	0	3	0	3	0	3	20	0	2	0	1	100	0	--	
Jul 8-12	TDGS 116% (110-120%)																	
surface (0-0.5 m)	22	0	19	10.5	5	0	5	0	0	0	--	--	--	--	--	--	--	
0-4 m	67	0	57	0	2	0	2	0	4	6.6	0	4	0	3	0	2	0	
deep (2-3 m)	14	0	5	0	3	66.7	3	0	8	61.5	0	8	0	7	57.1	6	0	
Jul 15-19	TDGS 114% (110-119%)																	
surface (0-0.5 m)	30	0	17	5.9	4	25	4	0	11	39.3	5	6	0	6	0	3	0	
0-4 m	68	0	41	0	3	0	3	0	11	21.2	0	11	0	10	10	5	0	
deep (2-3 m)	29	0	10	0	3	0	3	0	11	52.4	3	8	0	7	0	4	0	
Jul 22-26	TDGS 118% (114-122%)																	
surface (0-0.5 m)	43	0	33	9.1	5	40	5	0	8	19.5	0	8	0	5	40	2	0	
0-4 m	79	0	53	0	3	0	3	0	1	1.9	0	1	0	1	0	0	0	
deep (2-3 m)	35	0	21	0	3	0	3	0	0	0	--	--	--	--	--	--	--	
Jul 29-Aug 2	TDGS 116% (114-123%)																	
surface (0-0.5 m)	59	3.4	27	14.8	4	0	4	0	16	37.2	0	16	18.8	12	25	7	0	
0-4 m	99	0	71	0	2	0	2	0	1	1.4	0	1	0	1	100	0	--	
deep (2-3 m)	54	11.1	36	0	3	0	3	0	1	2.7	0	1	0	0	--	0	--	
Aug 5-9	TDGS 116% (110-122%)																	
surface (0-0.5 m)	38	2.6	23	4.3	4	25	4	0	6	20.7	0	6	33.3	6	16.7	1	0	
0-4 m	51	0	36	0	3	33.3	3	0	2	5.3	0	2	0	2	0	1	0	
deep (2-3 m)	28	3.6	17	0	3	0	3	0	0	0	--	--	--	--	--	--	--	

^a Fish placed in holding pen at beginning of experiment.^b Live fish removed from pen at end of experiment.^c External signs of GBD.^d Signs of GBD in the lateral line.^e Signs of GBD in brachial arteries and gill filaments.^f Number of dead fish that were too decomposed to examine for GBD signs.^g Number of fish with GBD.^h Average and range of TDGS during holding period (COE, Skamania).

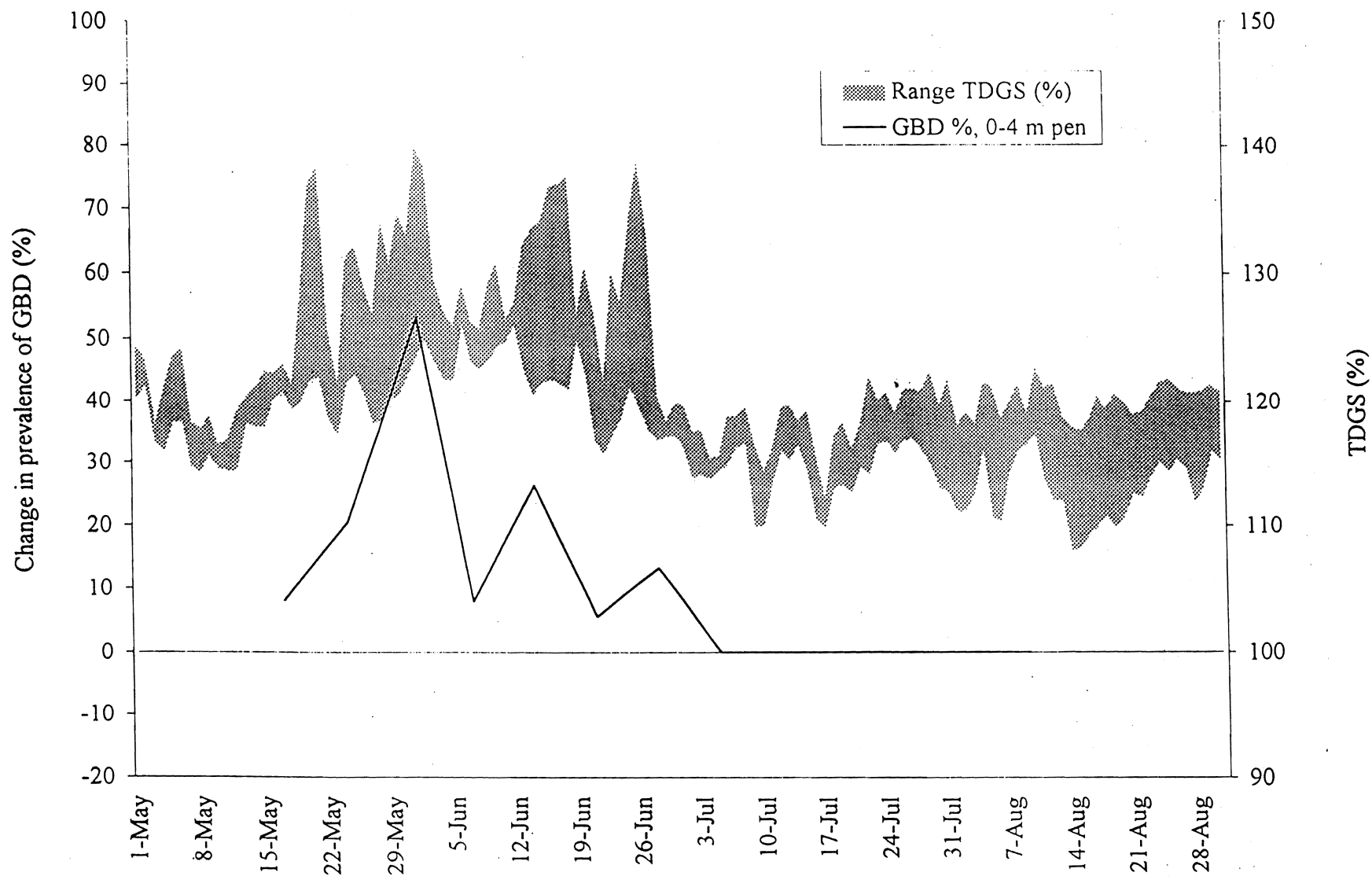


Figure 10. Change in GBD prevalence in resident fish held 4 days in river water downstream from Bonneville Dam compared with range of total dissolved gas saturation (TDGS) (COE, Skamania).

Priest Rapids Reservoir

Results of net-pen holding experiments with resident fish conducted upstream from Priest Rapids Dam are summarized in Table 12. External signs of GBD were observed among surviving resident fish held in the 0- to 0.5-m pen on 15 of the 16 4-day holding periods (prevalence range 20-100%) from 4 May through 16 August, when TDGS ranged from 111 to 137%. Fish held in the 0- to 4-m pen showed increases in external signs of GBD on 15 of the 16 holding periods (Fig. 11)(prevalence range 0-70%). External signs of GBD among resident fish held in the 2- to 3-m pen were observed on 6 of the 16 holding periods (prevalence range 0-75%).

There was no clear relationship between holding depth and prevalence of GBD signs in the lateral line or gills among surviving fish groups relative to holding depth. Prevalence of GBD signs in the lateral line among surviving fish removed from the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 100.0%, 0 to 66.7%, and 0 to 100.0%, respectively. Prevalence of GBD signs in gills ranged from 0 to 75.0%, 0 to 40.0%, and 0 to 66.7% for fish held in the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens, respectively.

In holding experiments where prevalence of GBD signs among surviving fish increased, that is, when GBD impacts affected captive fish, mortality among groups held in 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 90%, 0 to 33%, and 0 to 56%, respectively (Table 12).

Table 12. Gas bubble disease (GBD), mortality, and total dissolved gas saturation (TDGS) during net-pen experiments holding resident fish upstream from Priest Rapids Dam, 1996.

Date/ Conditions ^a	Introduction ^a external GBD		Survivors Examined ^b						Mortalities Examined								
			external ^c GBD		LL ^d GBD		gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD		gill ^e GBD	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)		(n)	(%)	(n)	(%)	(n)	(%)
TDGS ^h 123% (121-129%)																	
Apr 30-May 4 surface (0-0.5 m)	10	10	9	88.9	0	--	0	--	0	0	0	--	--	--	--	--	
0-4 m	154	9.7	149	42.3	0	--	0	--	10	6.3	4	6	16.7	5	20	5	0
deep (2-3 m)	9	0	8	0	0	--	0	--	0	0	0	--	--	--	--	--	
TDGS 119% (117-126%)																	
May 8-12 surface(0-0.5 m)	10	10	10	20	5	60	5	0	0	0	--	--	--	--	--	--	
0-4 m	114	2.9	111	4.5	0	--	0	--	1	0.9	0	1	100	1	100	1	100
deep (2-3 m)	10	20	9	22.2	5	20	5	0	1	10	1	--	--	--	--	--	
TDGS 121% (119-123%)																	
May 13-17 surface (0-0.5 m)	10	0	10	20	0	--	0	--	0	0	0	--	--	--	--	--	
0-4 m	93	9.7	83	16.9	0	--	0	--	3	3.5	0	3	0	0	--	0	--
deep (2-3 m)	10	0	10	0	0	--	0	--	0	0	0	--	--	--	--	--	
TDGS 127% (122-133%)																	
May 20-24 surface (0-0.5 m)	10	0	10	80	0	--	0	--	0	0	0	--	--	--	--	--	
0-4 m	154	7.1	134	40.3	0	--	0	--	7	5	1	7	42.9	0	--	0	--
deep (2-3 m)	10	0	10	0	0	--	0	--	0	0	0	--	--	--	--	--	
TDGS 127% (124-131%)																	
May 27-31 surface (0-0.5 m)	10	10	5	80	0	--	0	--	5	50	0	5	80	0	--	0	--
0-4 m	108	26.9	97	58.8	0	--	0	--	0	0	0	--	--	--	--	--	
deep (2-3 m)	10	20	10	0	0	--	0	--	0	0	0	--	--	--	--	--	
TDGS 127% (124-131%)																	
Jun 3-7 surface (0-0.5 m)	10	33.3	1	100	0	--	0	--	9	90	1	8	100	8	100	8	87.5
0-4 m	115	21.7	67	52.2	0	--	0	--	33	33	0	33	57.6	21	38.1	21	28.6
deep (2-3 m)	10	10	10	33.3	0	--	0	--	0	0	0	--	--	--	--	--	
TDGS 129% (123-132%)																	
Jun 10-14 surface (0-0.5 m)	10	20	1	100	1	0	1	0	9	90	0	9	88.9	9	100	9	44.4
0-4 m	144	12.5	105	59	5	20	5	20	30	22.2	8	22	59.1	22	54.5	22	13.6
deep (2-3 m)	10	10	8	0	5	40	5	0	2	20	0	2	0	2	0	2	0

Table 12. Continued.

Date/ Conditions ^a	Introduction ^a external GBD		Survivors Examined ^b						Mortalities Examined								
			external ^c GBD		LL ^d GBD		gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD		gill ^e GBD	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)				(n)	(%)	(n)	(%)	(n)	(%)
Jun 17-21	TDGS 128% (126-137%)																
surface (0-0.5 m)	10	0	0	--	--	--	--	--	10	100	3	7	100	7	100	7	57.1
0-4 m	86	2.3	64	59.4	5	40	5	40	22	25.6	5	17	11.8	14	42.9	14	0
deep (2-3 m)	10	0	8	0	3	100	3	66.7	2	20	0	2	0	1	0	1	100
Jun 24-28	TDGS 126% (120-132%)																
surface (0-0.5 m)	10	0	4	50	0	--	0	--	6	60	1	5	80	4	100	4	75
0-4 m	40	18	30	70	0	--	0	--	6	16.7	0	6	83.3	3	33.3	3	66.7
deep (2-3 m)	10	0	10	0	0	--	0	--	0	0	0	--	--	--	--	--	--
Jul 1-5	TDGS 119% (111-129%)																
surface (0-0.5 m)	10	0	8	37.5	4	25	4	75	2	20	0	2	100	0	--	0	--
0-4 m	42	9.5	35	17.1	5	0	5	0	3	7.9	3	0	--	0	--	0	--
deep (2-3 m)	10	0	10	0	5	20	5	0	0	0	--	--	--	--	--	--	--
Jul 8-12	TDGS 124% (120-130%)																
surface (0-0.5 m)	10	0	8	87.5	4	75	4	50	1	11.1	0	1	100	0	--	0	--
0-4 m	72	0	63	63.5	5	20	5	0	4	6	3	1	100	0	--	0	--
deep (2-3 m)	10	0	10	0	5	20	5	0	0	0	--	--	--	--	--	--	--
Jul 15-19	TDGS 121% (114-130%)																
surface (0-0.5 m)	10	33.3	6	83.3	2	100	2	50	4	40	2	2	100	1	100	1	100
0-4 m	52	17.3	29	31	0	--	0	--	14	32.6	9	5	20	3	100	3	33.3
deep (2-3 m)	10	0	4	75	3	0	3	66.7	5	55.6	2	3	33.3	2	50	2	50
Jul 22-26	TDGS 122% (116-128%)																
surface (0-0.5 m)	10	0	9	44.4	4	75	4	0	1	10	0	1	100	1	100	1	0
0-4 m	43	0	26	11.5	5	60	5	40	7	21.2	2	5	0	5	20	5	0
deep (2-3 m)	10	0	9	22.2	4	25	4	0	1	10	1	--	--	--	--	--	--
Jul 29-Aug 2	TDGS 117% (116-120%)																
surface (0-0.5 m)	10	0	8	37.5	3	33.3	3	33.3	2	20	2	--	--	--	--	--	--
0-4 m	45	0	34	5.9	5	0	5	0	6	15	6	--	--	--	--	--	--
deep (2-3 m)	10	0	10	0	5	0	5	0	0	0	--	--	--	--	--	--	--

Table 12. Continued.

Date/ Conditions ^a	Introduction ^a external GBD		Survivors Examined ^b							Mortalities Examined							
			external ^c GBD		LL ^d GBD		gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD		gill ^e GBD	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)		(n)	(%)	(n)	(%)	(n)	(%)
Aug 5-9									TDGS 114% (111-118%)								
surface (0-0.5 m)	10	0	9	55.6	4	50	4	25	1	10	0	1	0	1	0	1	0
0-4 m	17	0	15	0	3	66.7	3	0	1	6.3	1	--	--	--	--	--	--
deep (2-3 m)	10	0	7	14.3	3	66.7	3	33.3	2	22.2	2	--	--	--	--	--	--
Aug 12-16									TDGS 115% (111-117%)								
surface (0-0.5 m)	10	10	5	40	0	--	0	--	5	50	3	2	0	2	50	2	0
0-4 m	50	0	38	2.6	0	--	0	--	9	19.1	7	2	0	0	--	0	--
deep (2-3 m)	10	0	4	25	0	--	0	--	4	50	2	2	0	2	50	2	50

^a Fish placed in holding pen at beginning of experiment.^b Live fish removed from pen at end of experiment.^c External signs of GBD.^d Signs of GBD in the lateral line.^e Signs of GBD in brachial arteries and gill filaments.^f Number of dead fish that were too decomposed to examine for GBD signs.^g Pen depth.^h Average and range of TDGS during holding period (COE, Priest Rapids Dam forebay).

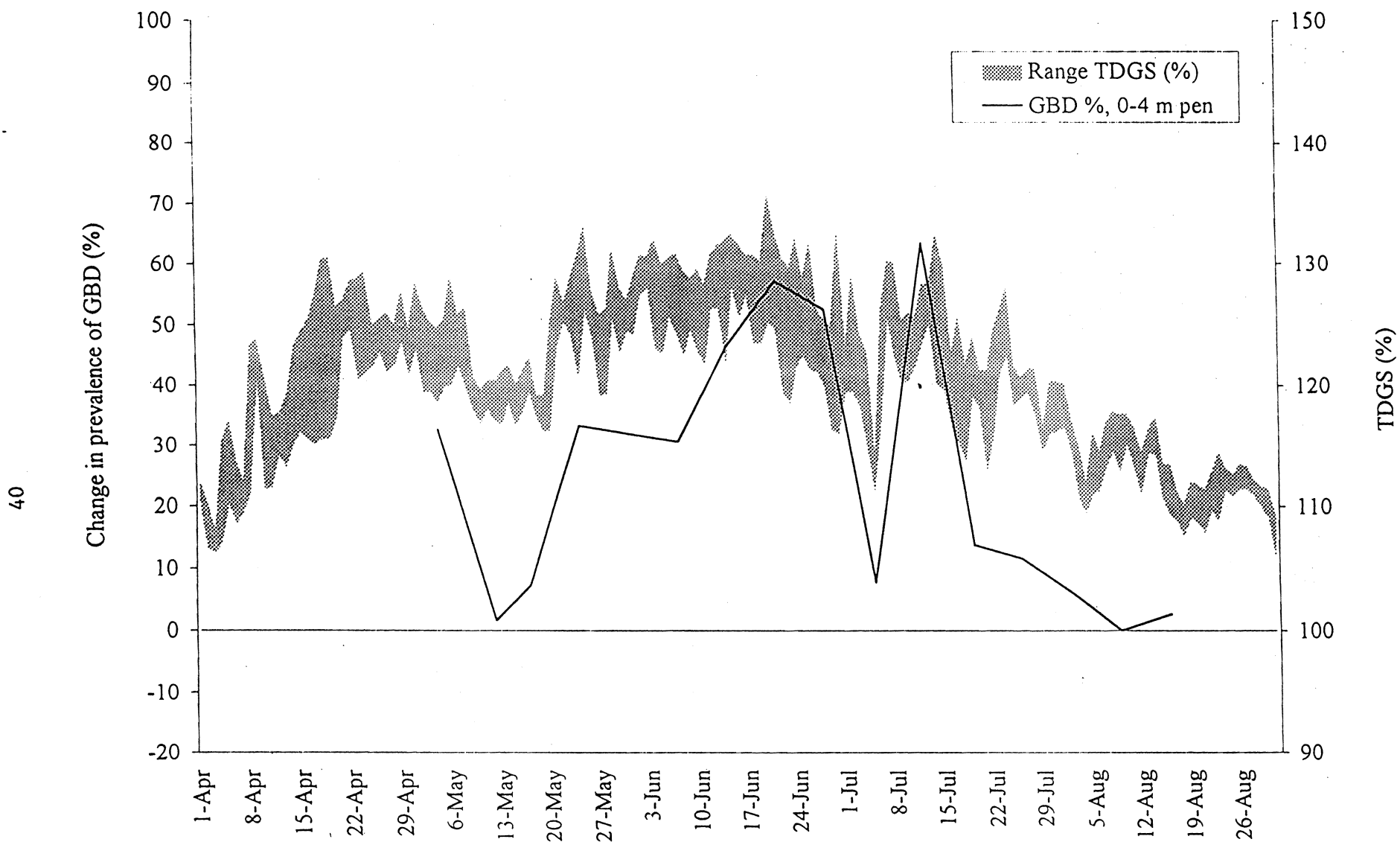


Figure 11. Change in GBD prevalence in resident fish held 4 days in river water in Priest Rapids Reservoir compared with range of total dissolved gas saturation (TDGS) (COE, Priest Rapids Dam forebay).

Downstream from Ice Harbor Dam

Results of net-pen holding experiments conducted downstream from Ice Harbor Dam with resident fish are summarized in Table 13. External signs of GBD were observed among surviving resident fish held in the 0- to 0.5-m pen in 11 of the 13 4-day holding periods (prevalence range 0-100%) from 18 May through 17 August, when TDGS ranged from 114 to 141%. Surviving fish held in the 0- to 4-m pen showed increased external signs of GBD in 9 of the 13 holding periods (Fig. 12)(prevalence range 0-86%). External signs of GBD among resident fish held in the 2- to 3-m pen were observed in 5 of the 13 holding periods (prevalence range 0-33%).

Prevalence of GBD signs in the lateral line among surviving fish removed from the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 100.0%, 0 to 66.7%, and 0 to 40.0%, respectively. There was no clear relationship between holding depth and prevalence of GBD signs in the gills among surviving fish groups. Signs of GBD in the gills were observed among fish groups removed from the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens on 5, 4, and 4 of the 15 4-day holding periods, respectively. Prevalence of GBD signs in the gills ranged from 0 to 80.0%, 0 to 60.0%, and 0 to 40.0% for fish held in the 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens, respectively.

In holding experiments where prevalence of GBD signs among surviving fish increased, that is, when GBD affected captive fish, mortality among groups held in 0- to 0.5-m, 0- to 4-m, and 2- to 3-m pens ranged from 0 to 90%, 4 to 40%, and 10 to 22%, respectively (Table 13).

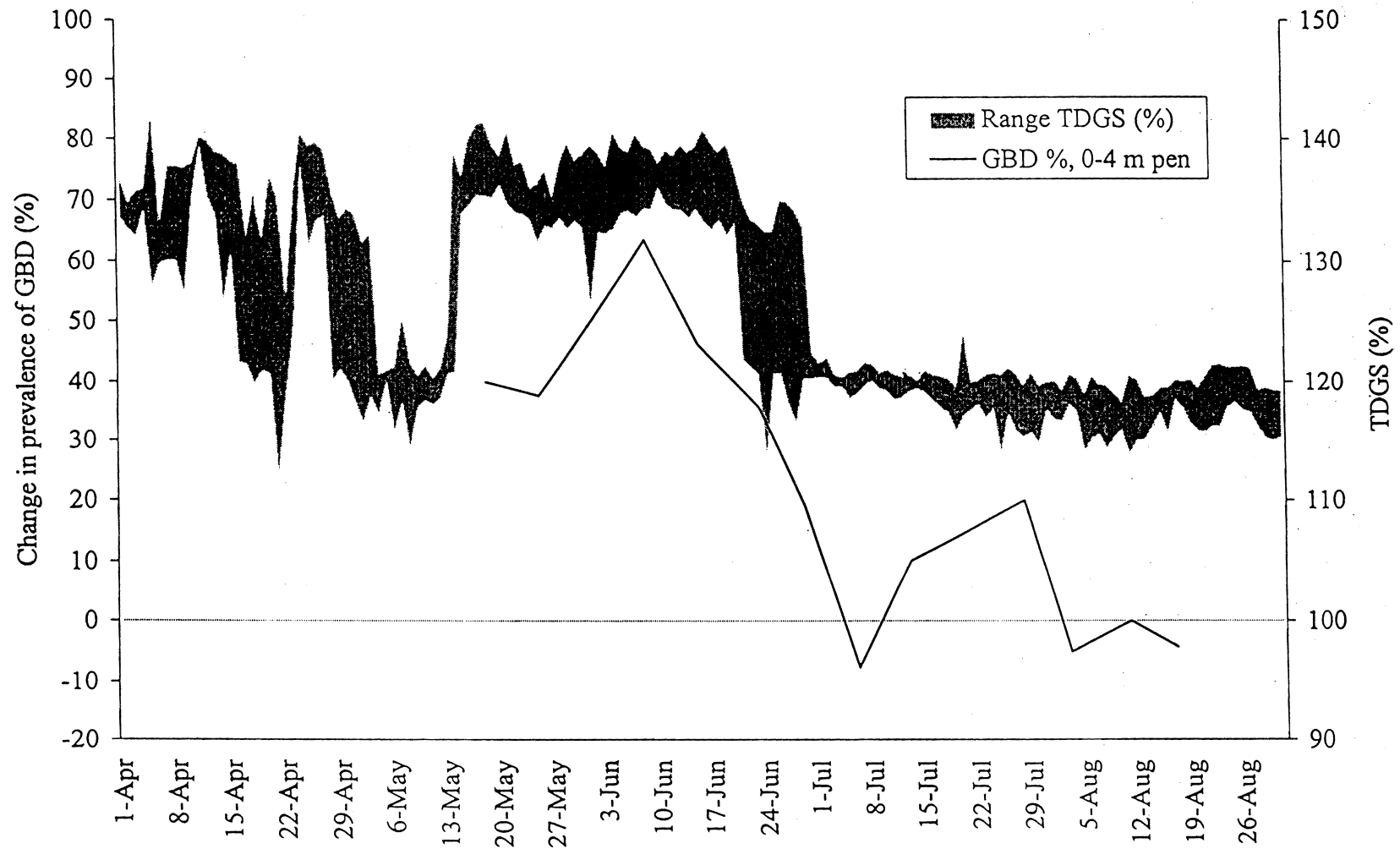


Figure 12. Change in GBD prevalence in resident fish held 4 days in river water downstream from Ice Harbor Dam compared with range of total dissolved gas saturation (TDGS) (COE, Ice Harbor Dam tailrace).

Table 13. Gas bubble disease (GBD), mortality, and total dissolved gas saturation (TDGS) during net-pen experiments holding resident fish downstream from Ice Harbor Dam, 1996.

Date/ Conditions ^a	Survivors Examined ^b								Mortalities Examined							
	Introduction ^a external ^c GBD		external ^c GBD		LL ^d GBD	gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD		gill ^e GBD	
	(n)	(%)	(n)	(%)	(%)	(n)	(%)				(n)	(%)	(n)	(%)	(n)	(%)
May 14-18	TDGS^h 136% (134-141%)															
surface (0-0.5 m)	10	10	2	50	--	0	--	8	80	0	8	87.5	8	75	8	25
0-4 m	35	0	30	40	--	0	--	5	14.3	1	5	40	5	40	5	0
deep (2-3 m)	10	10	6	0	--	0	--	3	33.3	0	3	0	3	33.3	3	0
May 21-25	TDGS 136% (133-141%)															
surface (0-0.5 m)	10	20	1	100	--	0	--	9	90	1	8	100	8	87.5	8	50
0-4 m	88	18.2	70	55.8	--	0	--	15	17.6	0	15	88.9	15	93.3	15	40
deep (2-3 m) ⁱ	10	30	1	100	--	0	--	9	90	0	9	100	9	100	9	55.6
May 28-Jun 1	TDGS 136% (127-140%)															
surface (0-0.5 m)	10	10	6	16.7	--	0	--	4	40	0	4	100	0	--	0	--
0-4 m	120	17.5	96	67.7	--	0	--	6	5.9	0	6	83.3	0	--	0	--
deep (2-3 m)	10	40	10	33.3	--	0	--	0	0	0	--	--	--	--	--	--
Jun 4-8	TDGS 137% (133-141%)															
surface (0-0.5 m)	10	40	0	--	--	--	--	10	100	0	10	80	0	--	0	--
0-4 m	58	22.4	51	86	66.7	6	33.3	2	3.8	0	2	50	0	--	0	--
deep (2-3 m)	10	20	9	10	20	5	0	0	0	0	--	--	--	--	--	--
Jun 11-15^j	TDGS 137% (134-140%)															
surface (0-0.5 m)	10	10	6	50	50	2	50	4	40	0	4	100	4	75	4	100
0-4 m	29	34.5	21	81	40	5	40	1	4.5	1	--	--	--	--	--	--
deep (2-3 m) ^k	10	10	2	0	0	2	0	0	0	0	--	--	--	--	--	--
Jun 19-23	TDGS 130% (121-140%)															
surface (0-0.5 m)	10	0	6	66.7	20	5	0	3	33.3	0	3	33.3	2	50	2	0
0-4 m	49	6.1	24	41.7	0	5	0	16	40	3	16	62.5	2	100	2	0
deep (2-3 m) ^l	10	0	9	22.2	40	5	0	1	10	1	--	--	--	--	--	--
Jun 25-29	TDGS 125% (120-135%)															
surface (0-0.5 m)	10	10	8	87.5	60	5	80	2	20	0	2	100	2	0	2	100
0-4 m	41	12.2	32	31.3	25	4	0	4	11.1	3	1	0	1	0	1	100
deep (2-3 m)	10	0	10	0	20	5	40	0	0	--	--	--	--	--	--	--
Jul 2-6	TDGS 121% (119-122%)															
surface (0-0.5 m)	11	0	9	0	22.2	9	0	0	0	--	--	--	--	--	--	--
0-4 m	39	7.7	29	0	--	0	--	1	3.3	0	1	0	0	--	0	--
deep (2-3 m)	6	0	6	0	0	1	0	0	0	--	--	--	--	--	--	--

Table 13. Continued.

Figure 15: Continued.

Date/ Conditions ^a	Introduction ^a external ^c GBD		Survivors Examined ^b						Mortalities Examined							
			external ^c GBD		LL ^d GBD	gill ^e GBD		Mortality		Decom. ^f	external ^c GBD		LL ^d GBD	gill ^e GBD		
	(n)	(%)	(n)	(%)	(%)	(n)	(%)				(n)	(%)	(n)	(%)	(n)	(%)
Jul 9-13	TDGS 120% (119-121%)															
surface (0-0.5 m)	10	0	8	25	100	4	50	1	11.1	0	1	100	1	100	1	100
0-4 m	67	3	61	13.1	50	6	33.3	5	7.6	1	4	0	4	0	4	0
deep (2-3 m)	10	0	6	16.7	25	4	50	1	14.3	0	1	0	1	0	1	0
Jul 16-20	TDGS 119% (116-124%)															
surface (0-0.5 m)	10	0	8	12.5	0	5	0	2	20	0	2	0	2	0	2	0
0-4 m ^m	28	0	4	0	--	0	--	14	77.8	9	5	0	1	100	1	0
deep (2-3 m)	10	0	10	0	--	0	--	0	0	--	--	--	--	--	--	--
Jul 24-28	TDGS 119% (114-121%)															
surface (0-0.5 m)	10	0	10	50	60	5	40	0	0	--	--	--	--	--	--	--
0-4 m	56	0	45	20	60	5	40	3	6.3	1	2	0	2	0	2	0
deep (2-3 m)	10	0	7	14.3	33.3	3	33.3	2	22.2	1	1	0	1	0	1	0
Jul 30-Aug 3	TDGS 119% (118-120%)															
surface (0-0.5 m)	10	0	8	0	0	3	0	0	0	--	--	--	--	--	--	--
0-4 m ⁿ	59	5.1	10	0	--	0	--	13	56.5	3	10	0	0	--	0	--
deep (2-3 m)	10	0	6	0	0	2	0	0	0	--	--	--	--	--	--	--
Aug 6-10	TDGS 117% (114-120%)															
surface (0-0.5 m)	10	0	10	20	50	4	50	0	0	--	--	--	--	--	--	--
deep (2-3 m)	10	0	8	0	25	4	25	2	20	2	--	--	--	--	--	--
Aug 7-11	TDGS 117% (114-121%)															
0-4 m	38	0	28	0	--	0	--	1	3.4	1	--	--	--	--	--	--
Aug 13-17	TDGS 117% (115-119%)															
surface (0-0.5 m)	10	0	7	14.3	100	1	0	2	22.2	1	1	0	1	0	1	0
0-4 m	23	4.3	19	0	--	0	--	4	17.4	4	--	--	--	--	--	--
deep (2-3 m)	8	0	1	0	0	1	0	0	0	--	--	--	--	--	--	--

^a Fish placed in holding pen at beginning of experiment.^b Live fish removed from pen at end of experiment.^c External signs of GBD.^d Signs of GBD in the lateral line.^e Signs of GBD in brachial arteries and gill filaments.^f Dead fish that were too decomposed to examine for GBD signs.^g Pen depth.^h Average and range of TDGS during holding period (COE, Ice Harbor Dam tailrace).ⁱ Ropes holding pen at depth came loose during fish holding. Pen found near surface.^j Fish were held in deep and shallow pens from 13-15 June.^k Eight fish from the deep pen presumably escaped through a hole found in the pen.^l Fish were held in the deep pen from 20-23 June.^m Damage to pen prevented fish recovery until 22 July. Signs of mammal predation observed.ⁿ Signs of mammal predation were observed.

Gas Bubble Disease Effects Model

We found that mortality in resident fish populations cannot be properly evaluated through sampling because dead fish were rarely observed in the lower Snake and Columbia Rivers; similar conclusions were made by (Merrell et al. 1971) wherein less than 5% of dead salmon released downstream of Bonneville Dam were observed. The 4-day holding tests in net-pens were intended as a surrogate for mortality evaluations among resident fish, but it appeared that impacts from GBD were greater for captive fish than for free-swimming fish. In 1995 and 1996, downstream from Ice Harbor Dam, average prevalence of external GBD signs for held fish was 13% greater (range from 25 to 50%) than for inriver fish sampled during the previous week. These results suggested that fish held in pens were not a good surrogate for inriver fish in assessment of prevalence of GBD. We therefore developed a model for predicting prevalence and severity of external signs of GBD in resident fish in relation to dissolved gas measurements in midriver. We then extrapolated GBD prevalence data to mortality estimates based on a relationship between percent GBD signs and percent mortality derived from our net-pen experiments.

Exposure vs. Gas Bubble Disease Signs

An exposure index describing effects of increasing, static, and decreasing exposure to total dissolved gas saturation for resident fish was developed by comparing data for external signs of GBD to midriver TDGS data (CROHMS). Few trials with TDGS less than 120% resulted in fish displaying signs of GBD. We speculated that depth distribution of resident fish generally provided sufficient compensation to prevent formation of external signs of GBD. Based on the 120% threshold, and on statistical trials with shorter and longer exposure periods, we adopted the

following scale for a 24-hour TDGS daily exposure ranking: 0 = <120%,

1 = 120-124.9%, 2 = 125-129.9%, 3 = 130-134.9%, 4 = 135-139.9%, 5 = 140-144.9%, and 6 = 145% or greater.

Several intervals over which the effects of TDGS were detrimental to resident fish were evaluated, including an index of TDGS exposure over the entire season. However, the narrowest confidence intervals were obtained by using daily ranks, beginning with the sampling day and including the 6 days prior to sampling. These daily ranks were summed to represent a 7-day cumulative exposure index (EI) (Table 14).

We used second-order polynomial regression to compare 7-day exposure index vs. percent GBD (external signs) (Fig. 13). This produced a strong relationship ($R^2 = 0.79$), leaving us confident that we had developed an EI that could reliably predict external signs of GBD in relation to TDGS exposure [$\%GBD = 0.05(EI)^2 + 0.21(EI) + 0.62$]. A bootstrapping technique was used to evaluate the statistical analysis, and it produced a nearly identical correlation. The same exposure index and second-order polynomial regression were used to predict external GBD signs of fry in relation to TDGS exposure. Once again this produced a strong relationship $R^2 = 0.82$ [$\%GBD = 0.050(EI)^2 + 2.83(EI) - 0.64$]; however, we caution that the fry model is only preliminary. There were only 10 samples containing fry (925 total); all were collected below Bonneville Dam in 1996.

Algorithms relating TDGS to percent GBD signs are currently being developed for individual species (smallmouth bass, yellow perch, and peamouth) that display promise for relating percent GBD signs to mortality. Preliminary equations and correlation coefficients for those

Table 14. Ranking scale and example of the exposure index used to establish impacts of total dissolved gas saturation (TDGS) on resident fish.

<u>Scale</u>		<u>Example</u>			
%TDGS	Daily rank ^a	Date	%TDGS ^b	Daily rank ^a	Exposure index
100-119%	0	Day 6	135	4	--
120-124%	1	Day 5	131	3	--
125-129%	2	Day 4	124	1	--
130-134%	3	Day 3	128	2	--
135-139%	4	Day 2	120	1	--
140-144%	5	Day 1	118	0	--
		Day 0 ^d	122	1	12

Sample Data Below Ice Harbor Dam 1996

Date	%TDGS	Daily rank ^a	Exposure index ^c	Daily sample (%GBD) ^d
23 Apr	122.0	1		
24 Apr	138.9	4		
25 Apr	137.0	4		
26 Apr	136.2	4		
27 Apr	135.8	4		
28 Apr	129.7	2		
29 Apr	125.4	2	21	37.8%
30 Apr	126.5	2		
1 May	123.2	1		
2 May	121.3	1		
3 May	121.5	1		
4 May	118.6	0		
5 May	120.6	1		
6 May	118.7	0	6	5.5%
7 May	120.9	1		
8 May	118.9	0		
9 May	119.7	0	3	7.8%

^a Daily rank base on 24-hour mean midriver TDGS (CROHMS).

^b Average daily TDGS near the fish sampling site (CROHMS data).

^c Index based on sum of daily ranks for the sampling day and 6-days prior.

^d Percent of sampled fish displaying external signs of gas bubble disease.

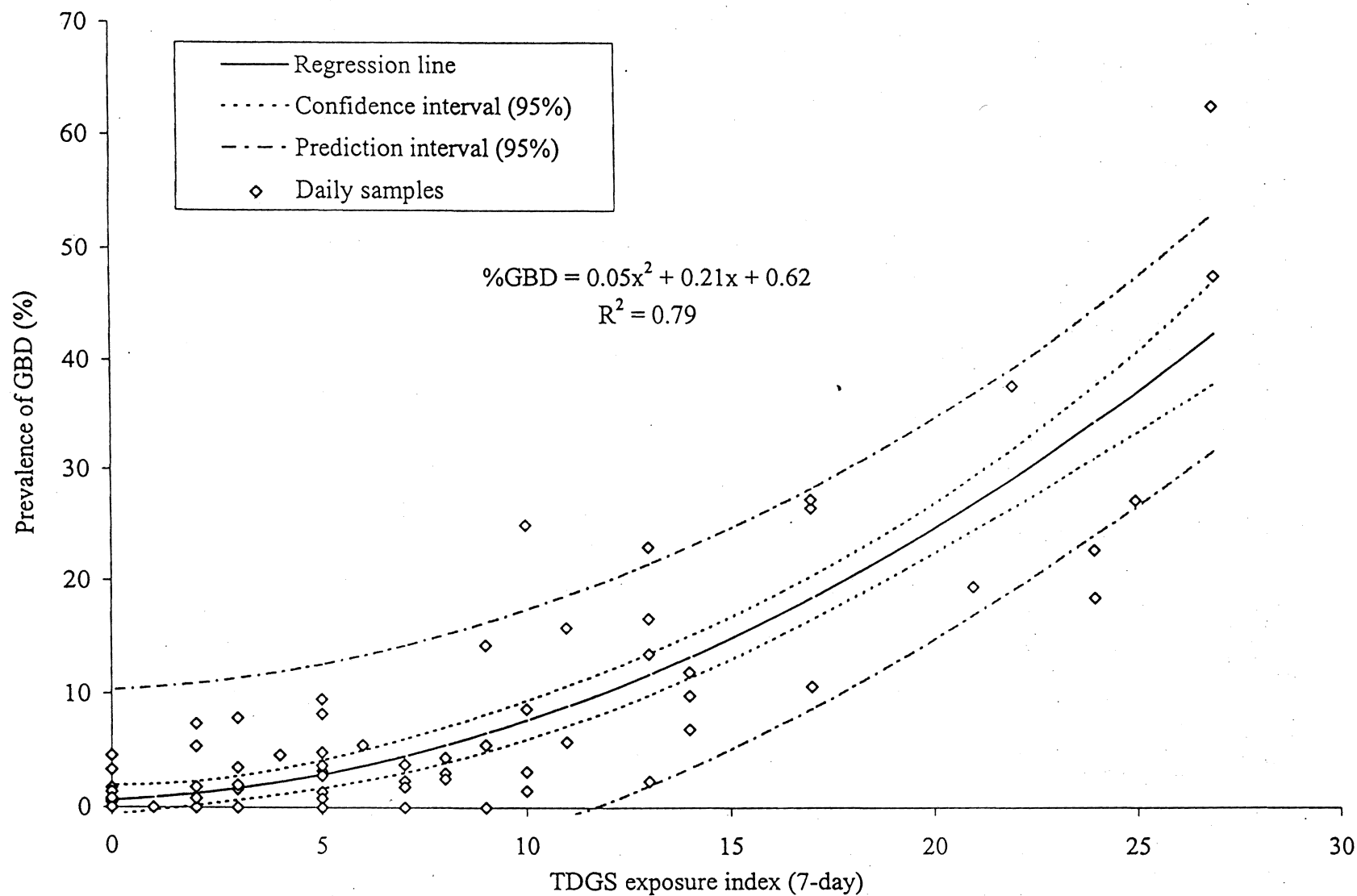


Figure 13. Prevalence of GBD in resident fish collected from the Snake and Columbia rivers compared with 7-day TDGS exposure index (1995-96).

algorithms were $R^2 = 0.45$ [%GBD = $0.0003(EI)^2 + 0.0064(EI) - 0.0016$] for smallmouth bass, $R^2 = 0.68$ [%GBD = $0.0009(EI)^2 - 0.0062(EI) + 0.0065$] for yellow perch, and $R^2 = 0.36$ [%GBD = $0.0002(EI)^2 - 0.001(EI) + 0.0002$] for peamouth. The individual species models were also developed using small sample sizes, and it should be stressed that these results are preliminary.

Gas Bubble Disease Signs vs. Mortality

In 1995, regression analysis explained 54% of the observed variability between prevalence of external GBD signs and percent mortality, using all fish species held in net-pens. Although the resulting R^2 value (0.54) reflected a significant correlation, we assumed that it was anomalous because the data were distributed at two extremes. When we combined data from 1994, 1995, and 1996 for all fish species, the resulting regression showed no significant relationship. While most fish species did not show a clear relationship between prevalence of GBD signs and percent mortality, due to either small sample size or species-specific behavior, a few species showed promising results.

The strongest relationship between prevalence of external GBD signs and percent mortality was for smallmouth bass: $R^2 = 0.52$ [% mort = $0.14 \times \log (\% \text{ GBD}) + 0.20$]. However, because of the small sample size and a protracted distribution of data, the relationship was not significant. Peamouth and yellow perch showed a trend, but sample sizes were limited. By combining data for the three species, data distributions were improved (Fig. 14). The combined data were evaluated using linear regression and produced the following algorithm: [% mort = $(2.24 \times \sqrt{\text{GBD}\%}) - 3.51$], $R^2=0.41$. While this may not explain all of the mortalities, it does at least show some promise. It is not clear whether additional data will show a stronger relationship.

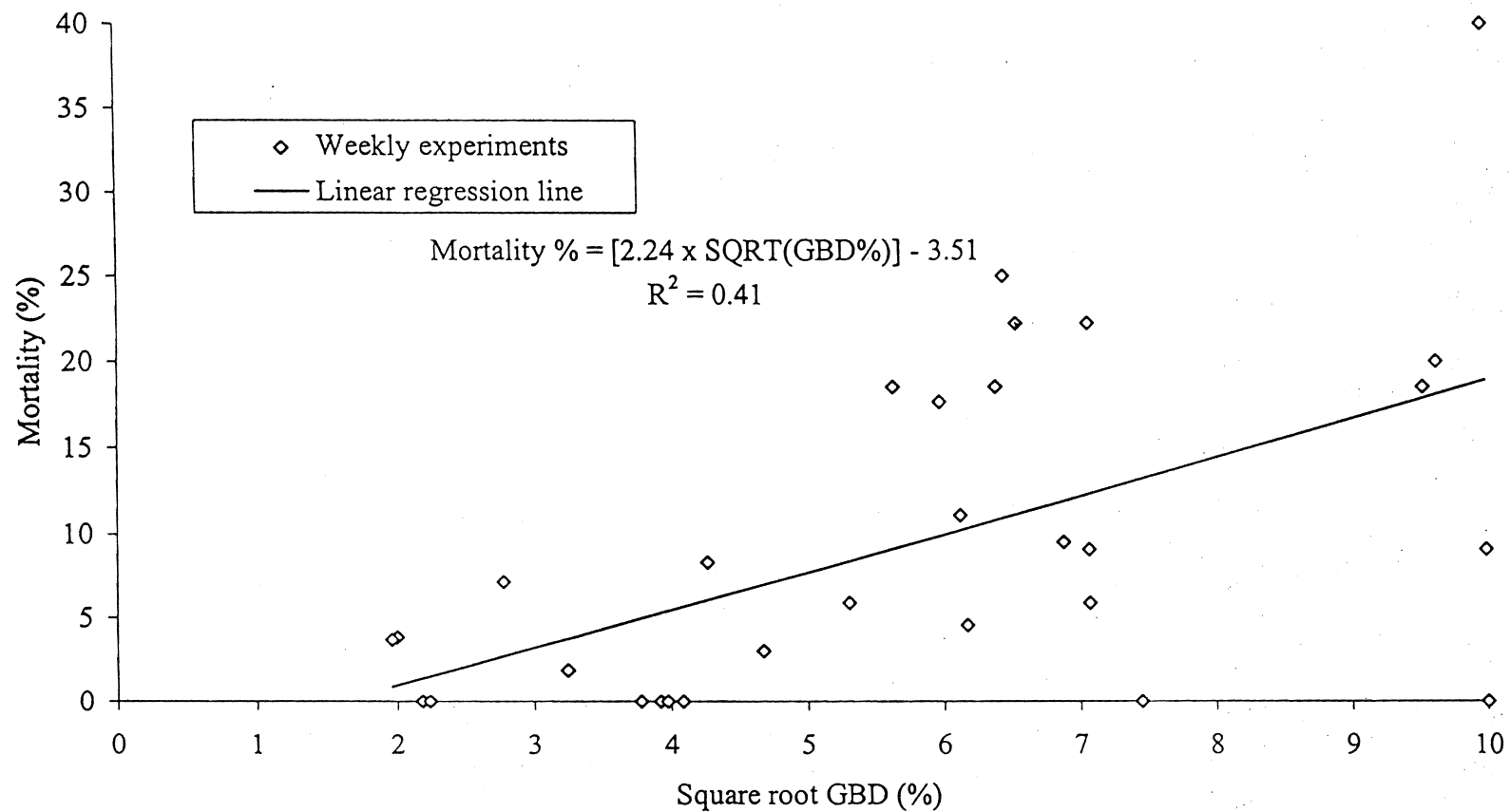


Figure 14. Percent mortality of resident fish held in net-pens in the Snake and Columbia rivers regressed against the square root of percent GBD signs on live fish at the conclusion of each 4-day holding period (1995-96).

DISCUSSION

Comparison to 1995 GBD Study

Downstream from Bonneville Dam in 1995, the daily average TDGS in midriver ranged from 116 to 117%. External signs of GBD were observed on 8 and 29 June, when TDGS peaked at 118% at the sampling site and 122% in the river channel (Schrunk et al. 1996). In 1996 at these same locations, daily average TDGS in midriver ranged from 111 to 130%. Signs of GBD were observed in resident fish on 28 occasions from 15 March to 12 August. The highest prevalence of GBD occurred during a 10-day period from 3 to 13 June, when up to 16% of fish sampled displayed external signs of GBD and the daily average TDGS in midriver ranged between 123 and 128%, and TDGS at sampling sites ranged between 121 and 126%.

In Priest Rapids Reservoir during 1995, spill at Wanapum Dam caused high TDGS during May and early June; up to 124.2% in midriver and 123.7% at local sampling sites. Prevalence of external signs of GBD was low, ranging from 0 to 5.4% among resident fish. In 1996, daily average TDGS reached 132% and was high from mid-April to mid-June. Prevalence of external GBD signs among sampled resident fish ranged from 2 to 23% through that period.

In 1995 below Ice Harbor Dam, daily average TDGS during peak spill was near 128-130% from mid-May to mid-June. High prevalence of GBD (11 to 41%) was observed during this period, but relatively few instances of GBD were observed in the weeks after daily average TDGS had fallen to (and remained at) 118% or less. In 1996, daily average TDGS during peak spill was near 135% from mid-May to mid-June. As in 1995, high prevalence of GBD (18 to

36%) was observed during that period, but prevalence dropped as daily average TDGS fell near or below 120%.

Gas Bubble Disease Effects Model

We believe that the algorithm relating external GBD signs to TDGS exposure is complete and accurate for fish residing in shallow waters of the Columbia River Basin. However, computed GBD impacts only pertain to those portions of the river where dissolved gas levels are represented by TDGS monitoring data. Areas of lower dissolved gas (by model definition 7% less) at shoreline peripheries are not properly represented by the TDGS monitoring data. In general, slack water areas cause less risk of GBD to resident fish than the main river.

The algorithm relating GBD signs to mortality was not as precise because there appeared to be species-specific behavior that caused high variability for net-pen mortality in multispecies tests. Species such as suckers, sculpin, and catfish commonly reside on the bottom, and the environment they came from may have been shallow enough for TDGS to have an impact. However, the bottom of our net-pen was 4 meters deep, and therefore provided compensation for TDGS up to 138% at the surface. Other species of fish such as smallmouth bass, yellow perch, and peamouth are not bottom dwellers and were more likely to establish a depth similar to that occupied before they were captured. To evaluate this problem, we split the residents into groups: first by species and then by behaviors. While we found no clear relationship for all residents, smallmouth bass, yellow perch, and peamouth showed less variability. We intend to continue tests focusing on these as indicator species.

CONCLUSIONS AND RECOMMENDATIONS

1) The algorithm relating GBD signs to TDGS exposure can accurately predict signs in resident fish where continuous TDGS readings are available; therefore we believe the extensive sampling of all species to monitor signs of GBD is no longer necessary. Sampling should be continued only on individual species of interest and on a small scale to ensure the accuracy of our model.

2) An algorithm relating mortality to GBD signs is not precise, partly due to the effect of combining all sampled species, but separate algorithms by individual species show promise. The holding experiments should be conducted for one more season in areas with consistently high TDGS (>120%), and where sufficient numbers of smallmouth bass, yellow perch, and peamouth can be sampled.

3) We captured fish fry near the water surface; fry that resided deeper in the water column were not targeted. Because of their unusually high position in the water column and their developmental stage, fry are more susceptible to TDGS and were differentiated from mature fish. However, due to limited data, our model relating GBD signs in fry to TDGS should not be relied upon without further sampling and model upgrading.

ACKNOWLEDGEMENTS

We thank Lila Charlton, Paul Smith, Craig Zaugg, Michael Cloninger, and Rick De La Brittonne for their long hours spent in field sampling, often under adverse conditions. We are indebted to Rick Nelson and Dennis Enright for their efforts in construction of equipment and in field sampling.

REFERENCES

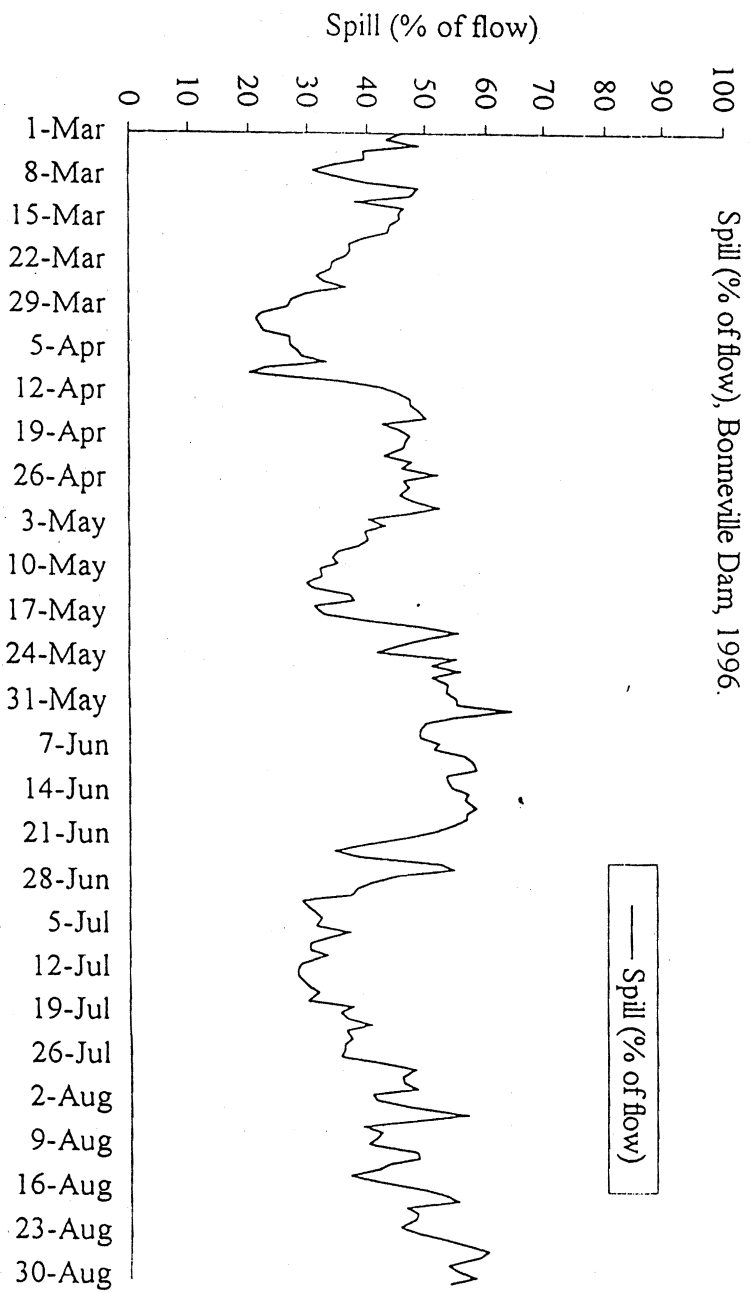
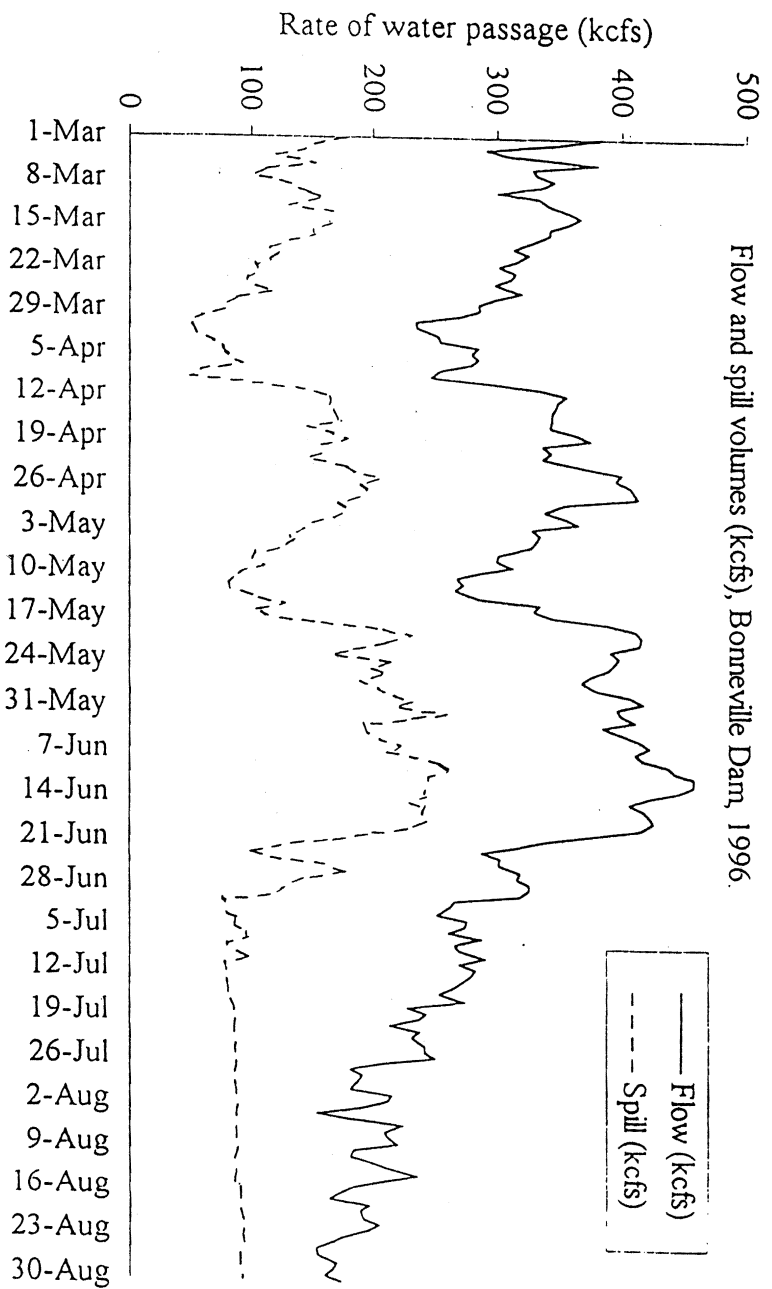
- Bennett, D. 1994. Abundance, habitat, and migration of age 0 fall chinook salmon in the lower Snake River reservoirs. Abstract presented to U.S. Army Corps of Engineers Fish Passage Development and Evaluation Program, 1994 Annual Program Review, (Available from U.S. Army Corps of Engineers, Portland District, P.O. Box 2946 Portland, OR 97208-2946.)
- Berggren, T.J., and M.J. Filardo. 1993. An Analysis of Variables Influencing The Migration of Juvenile Salmonids in the Columbia River Basin. *N. Am. J. Fish. Manage.* 13:48-63.
- Brammer, J. A. 1991. The effects of supersaturation of dissolved gases on aquatic invertebrates of the Bighorn River downstream of Yellowtail Afterbay Dam. Master of Science Thesis, Montana State University, Bozeman, 132 p.
- D'Aoust, B. G., R. White, and H. Siebold. 1976. An electronic monitor for total dissolved gas pressure. *In* D. H. Fickeisen and M. J. Schneider (editors), Gas bubble disease, p. 106-110. CONF-741033. Technical Information Center, Energy Research and Development Administration, Oak Ridge, TN.
- Dawley, E. M. 1986. Effect of 1985-86 levels of dissolved gas on salmonids in the Columbia River. Report to U.S. Army Corps of Engineers, Contract DACW57-85-F-0623, 31 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)
- Dawley, E. M., B. H. Monk, M. H. Schiewe, T. W. Newcomb, F. J. Osslander, and W. J. Ebel. 1976. Effects of long-term exposure to supersaturation of dissolved atmospheric gases on juvenile chinook salmon and steelhead trout in deep and shallow test tanks. *In* D. H. Fickeisen and M. J. Schneider (editors), Gas bubble disease, p. 1-10. CONF-741033. Technical Information Center, Energy Research and Development Administration, Oak Ridge, TN.
- Dell, M. B., M. W. Erho, and B. D. Leman. 1974. Occurrence of gas bubble disease symptoms on fish in mid-Columbia River reservoirs. Internal report, Grant County PUD, 49 p. (Available from Public Utility District of Grant County, Ephrata, WA 98823.)
- Ebel, W. J. 1969. Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. *U.S. Fish Wildl. Serv., Fish Bull.* 68:1-11.
- Ebel, W. J., and H. L. Raymond. 1976. Effect of atmospheric gas supersaturation on salmon and steelhead trout of the Snake and Columbia Rivers. *U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev.* 7:1-14.

- Ebel, W. J., H. L. Raymond, G. E. Monan, W. E. Farr, and G. K. Tanonaka. 1975. Effects of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia Rivers. Processed Report, 111 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)
- Fidler, L. E., and S. B. Miller. 1993. British Columbia water quality guidelines for dissolved gas supersaturation. Draft report to B.C. Ministry of Environment, Canada Department of Fisheries and Oceans, 94 p., plus appendix. (Available from B.C. Ministry of Environment, Water Quality Branch, Water Management Division, 765 Broughton St., Victoria, B.C. V8V1X5).
- Merrell, T. R. Jr., M. D. Collins, and J. W. Greenough. 1971. An estimate of mortality of chinook salmon in the Columbia River near Bonneville Dam during the summer run of 1955. U.S. Fish Wild. Serv., Fish Bull. 68:3:461-492.
- Montgomery Watson. 1995. Allowable gas supersaturation for fish passing hydroelectric dams. Task 8 - Bubble reabsorption in a simulated smolt bypass system - concept assessment. Report to Bonneville Power Administration, Contract Number DE-AC79-93BP66208 Report number 3009001. 7 p., plus appendixes. (Available from Bonneville Power Administration, Portland OR 97208.)
- Nebeker, A. V., D. G. Stevens, and J. R. Brett. 1976. Effects of gas supersaturated water on freshwater aquatic invertebrates. In D. H. Fickeisen and M. J. Schneider (editors), Gas bubble disease, p. 51-65. CONF-741033. Technical Information Center, Energy Research and Development Administration, Oak Ridge, TN.
- Schoeneman, D. E., R. T. Pressey, and C. O. Junge. 1961. Mortalities of downstream migrant salmon at McNary Dam. Trans. Am. Fish. Soc. 90:58-72.
- Schrank, B. P., B. A. Ryan, and E. M. Dawley. 1996. Evaluation of the effects of dissolved gas supersaturation on fish and invertebrates in Priest Rapids Reservoir, and downstream from Bonneville and Ice Harbor Dams, 1995. Report to the U.S. Army Corps of Engineers, Contract E96940029, (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)
- Stroud, R. K. and A. V. Nebeker. 1976. A study of the pathogenesis of gas bubble disease in steelhead trout (*Salmo gairdneri*). In D. H. Fickeisen and M. J. Schneider (editors), Gas bubble disease, p. 66-71. CONF-741033. Technical Information Center, Energy Research and Development Administration, Oak Ridge, TN.

- Toner, M. A., E. M. Dawley, and B. Ryan. 1995. Evaluation of the effects of dissolved gas supersaturation on fish and invertebrates downstream from Bonneville, Ice Harbor, and Priest Rapids Dams, 1994. Report to the U.S. Army Corps of Engineers, Contract E96940029, 43 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)
- White, R. G., G. Phillips, G. Liknes, J. Brammer, W. Conner, L. Fidler, T. Williams, and W. Dwyer. 1991. Effects of supersaturation of dissolved gases on the Fishery of the Bighorn River downstream of the Yellowtail afterbay dam. Report to the U.S. Bureau of Reclamation, 708 p. (Available from Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, MN.)
- Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Trans. Am. Fish. Soc. 109:659-702.
- Wydowski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington, University of Washington Press. 220 p.

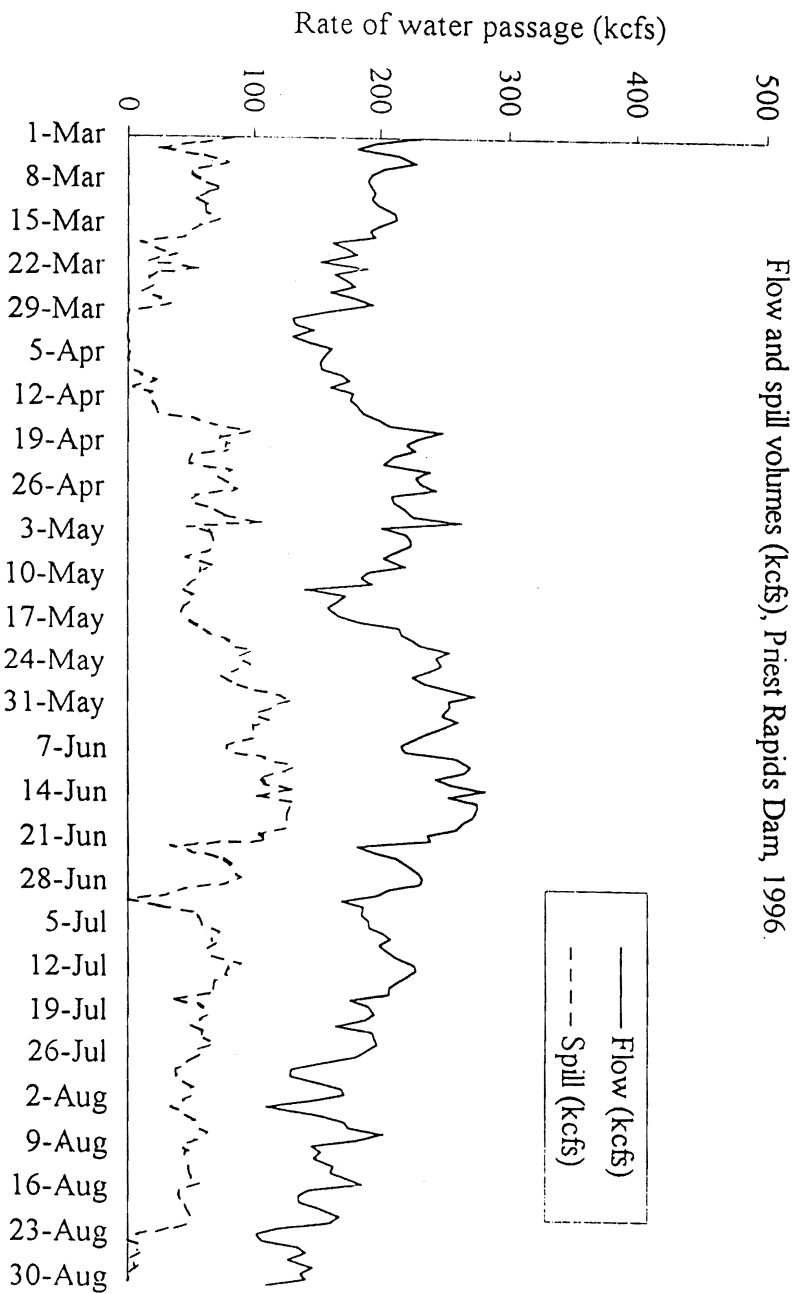
APPENDICES

Appendix Figure 1.....	1996 flow data, Bonneville Dam
Appendix Figure 2.....	1996 flow data, Priest Rapids Dam
Appendix Figure 3.....	1996 flow data, Wanapum Dam
Appendix Figure 4.....	1996 flow data, Ice Harbor Dam

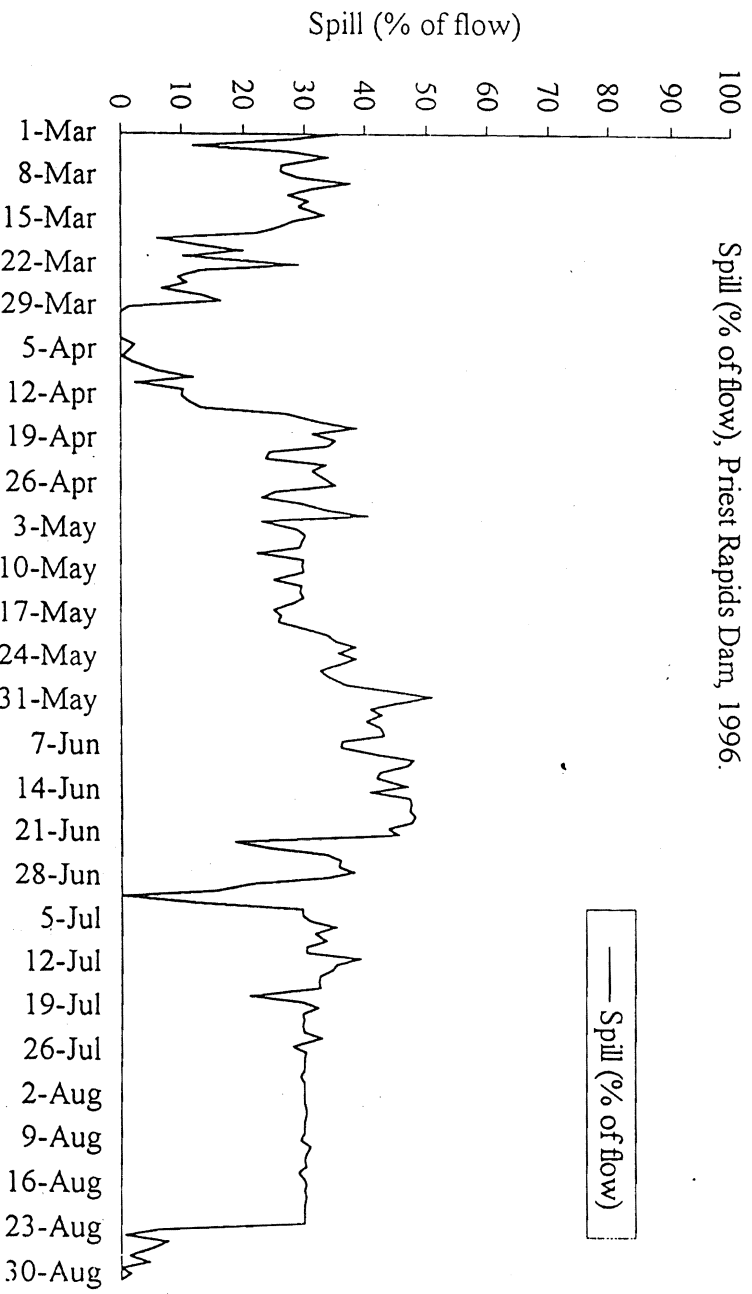


Appendix Figure 1. Flow, spill, and % spill at Bonneville Dam, 1996
(data provided by COE).

Flow and spill volumes (kcfs), Priest Rapids Dam, 1996.

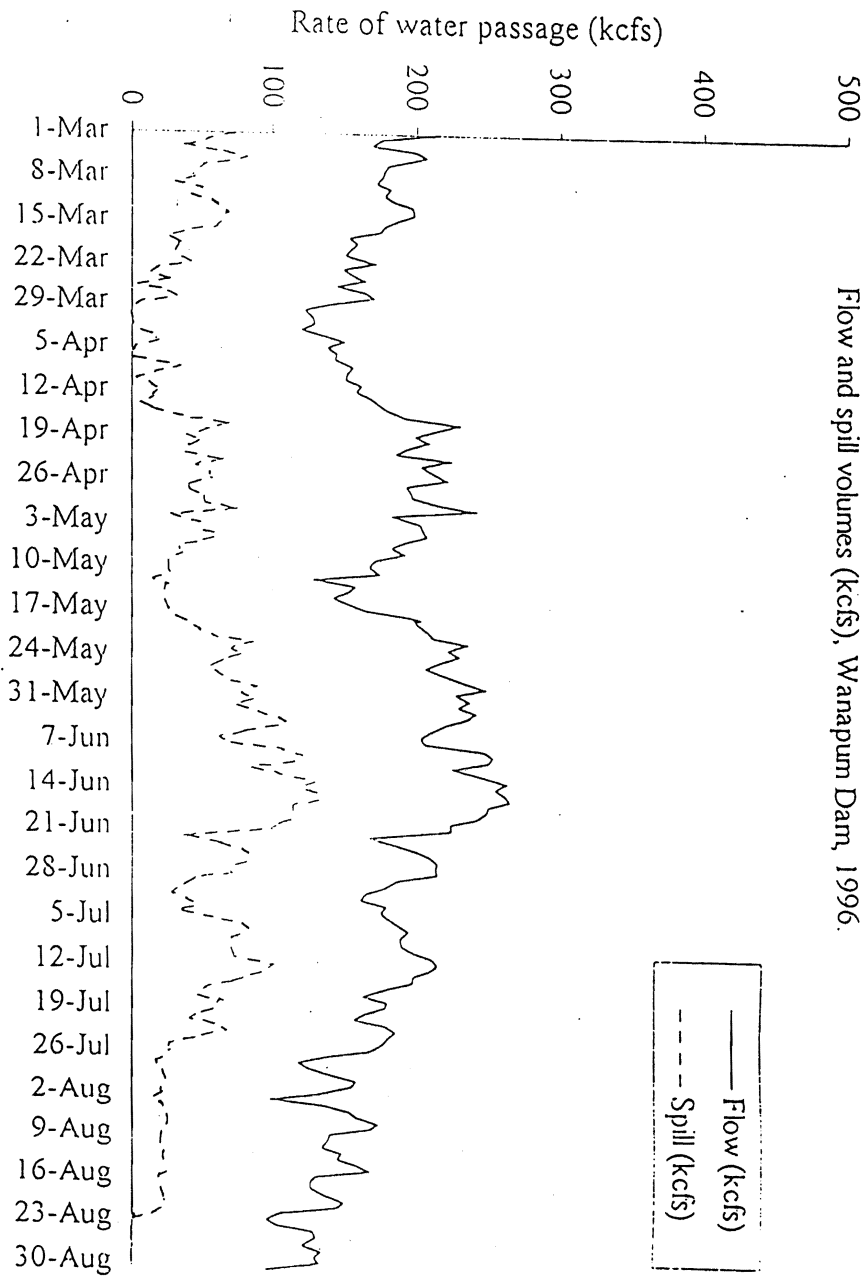


Spill (% of flow), Priest Rapids Dam, 1996.

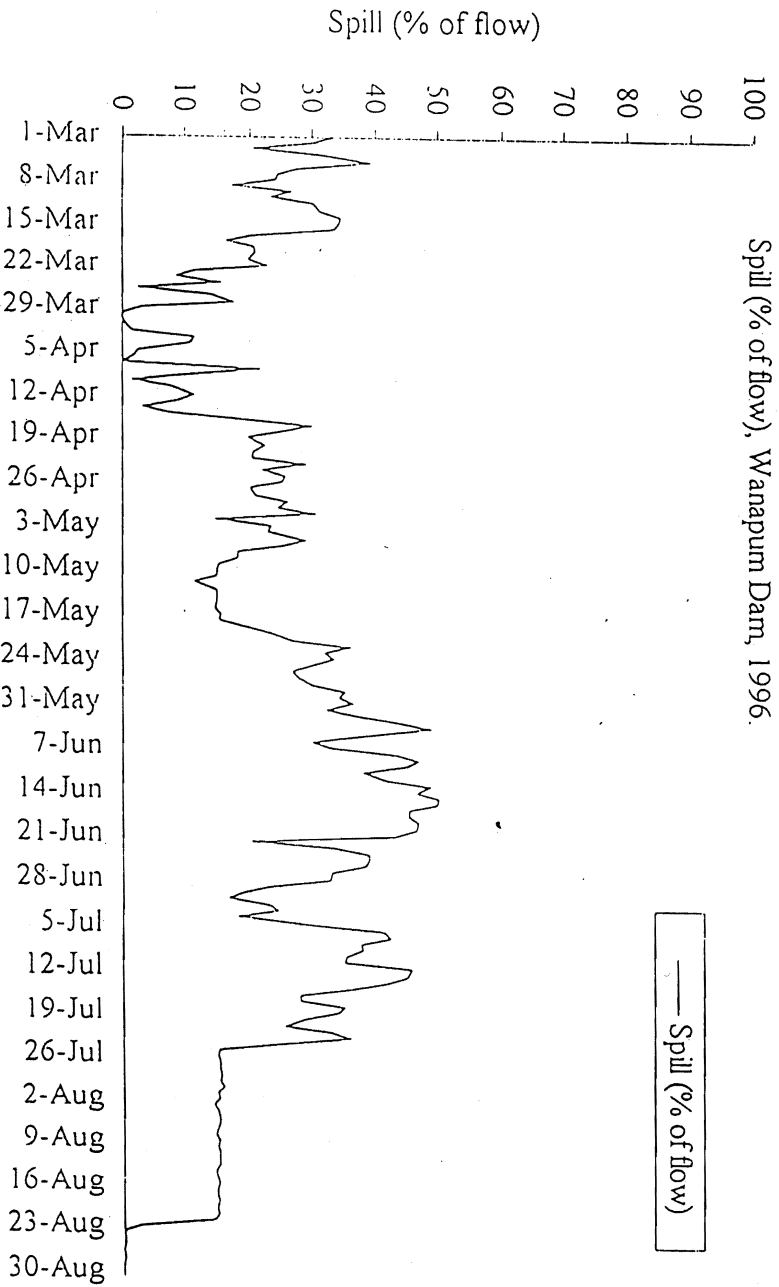


Appendix Figure 2. Flow, spill, and % spill at Priest Rapids Dam, 1996 (data provided by COE).

Flow and spill volumes (kcfs), Wanapum Dam, 1996.

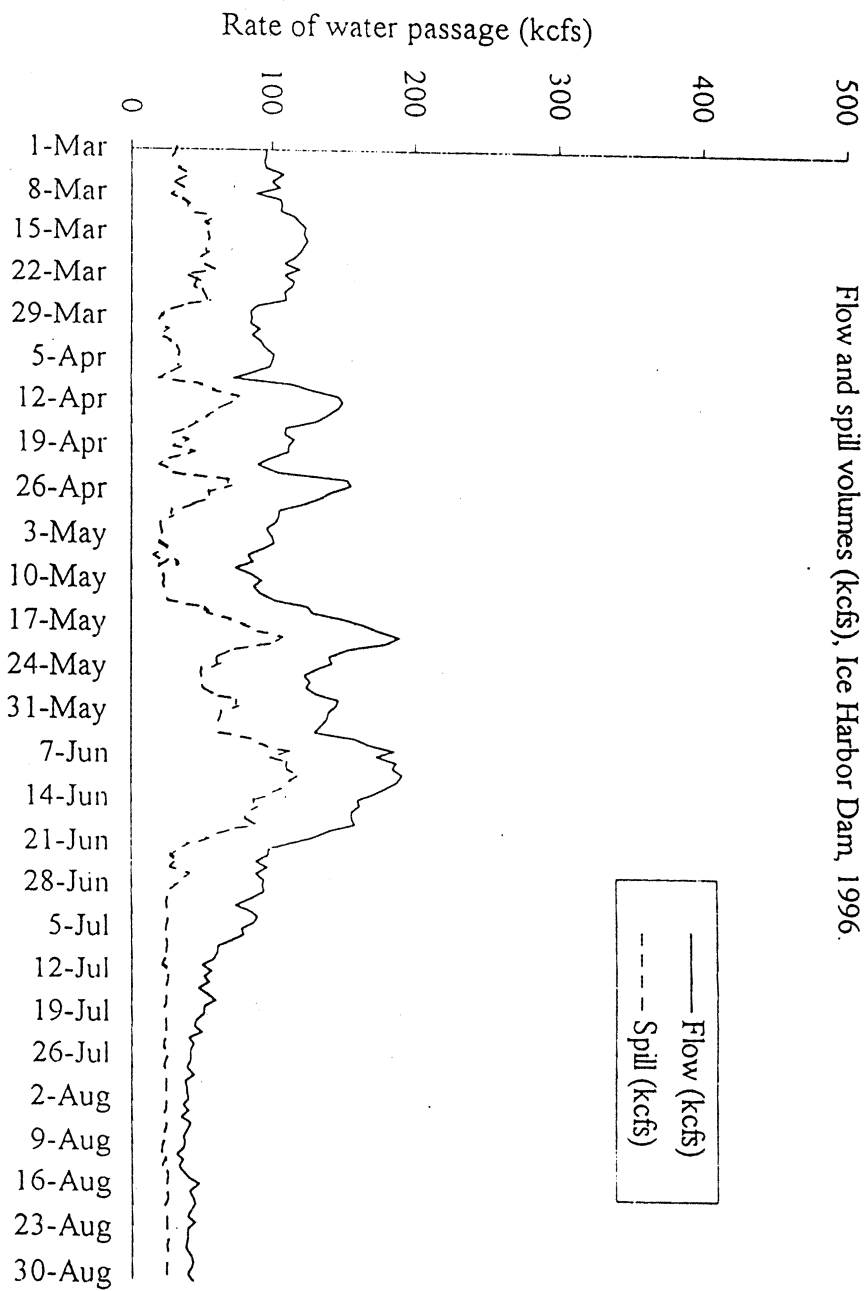


Spill (% of flow), Wanapum Dam, 1996.

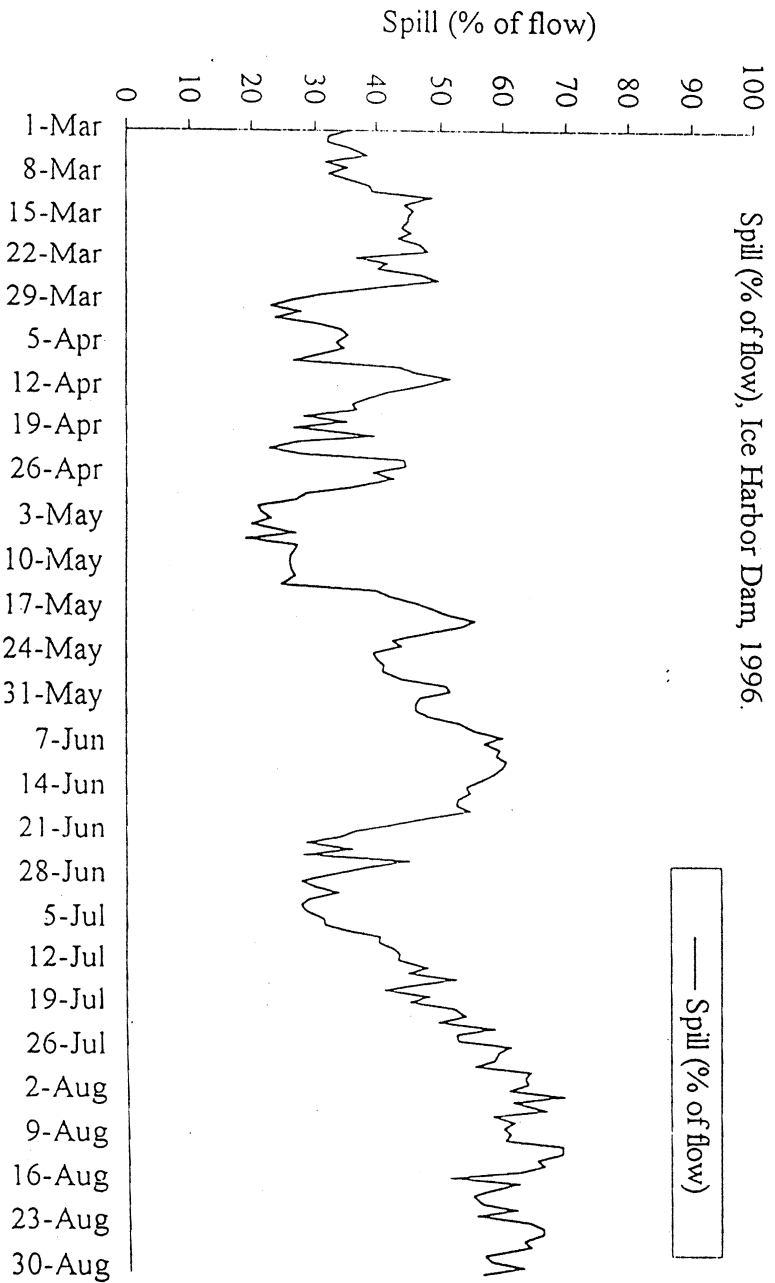


Appendix Figure 3. Flow, spill, and % spill at Wanapum Dam, 1996
(data provided by COE).

Flow and spill volumes (kcfs), Ice Harbor Dam, 1996.



Spill (% of flow), Ice Harbor Dam, 1996.



Appendix Figure 4. Flow, spill, and % spill at Ice Harbor Dam, 1996
(data provided by COE).