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

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Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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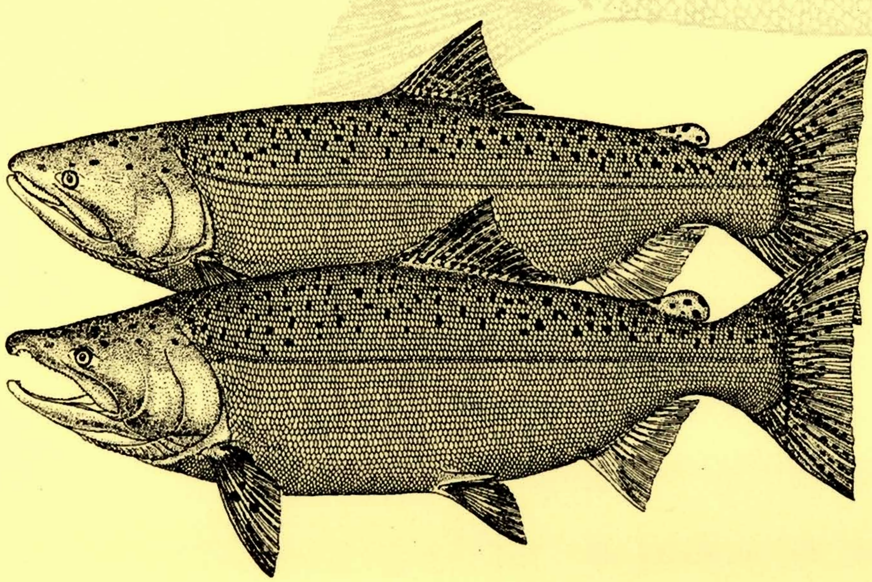
July 1997



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

by

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EXECUTIVE SUMMARY

Dissolved gas supersaturation in excess of state and federal water quality criteria is commonly occurring in the Columbia and Snake Rivers in association with increased spill at dams. These increased spill levels are intended to provide safe passage of migrating juvenile salmon. However, supersaturation resulting from spill in past decades has led to gas bubble disease (GBD) in fish. Therefore, during the period of high spill in 1995, we monitored the prevalence and severity of GBD by sampling fish and invertebrates downstream from Bonneville and Ice Harbor Dams and upstream from Priest Rapids Dam. Visual examination of organisms for our primary assessment of external GBD signs (subcutaneous emphysema on fins, head, eyes, and body surface) was carried out using 2.5- to 5-power magnification lenses.

Subsamples of invertebrates and resident nonsalmonid fish species were held in net-pens for 4 days and then reexamined for prevalence and severity of GBD. Additionally, hatchery-reared subyearling fall chinook salmon (*Oncorhynchus tshawytscha*) obtained from Bonneville Hatchery were held in net-pens downstream from Bonneville Dam and downstream from Ice Harbor Dam. Three types of net-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 an inclined bottom which extended from the surface to a depth of 4 m.

From 13 April to 15 August, we examined 84 salmonid fishes, 7,272 nonsalmonid fishes, and 1,303 invertebrates for signs of GBD. Few signs of GBD among invertebrates collected from monitoring sites were observed. Signs of GBD in fish were prevalent downstream from Ice Harbor Dam but were rare in the other river reaches sampled. Dissolved gas supersaturation (DGS) was extremely high downstream from Ice Harbor Dam between 8 May and 20 June as a

result of turbine outages at Ice Harbor Dam. Because of limited turbine capacity, levels of spilled water[1] reached as high as 76,700 ft^3/sec and approached 53% of total river flow. DGS reached 138% of saturation and was near or above 130% for most of this period. Signs of GBD were observed in 20% of resident fish captured during this time; nearly half of these fish displayed severe signs (greater than 25% of a fin showing emphysema and/or other body surfaces showing emphysema). Eleven of the 22 species captured displayed signs of GBD.

Upstream from Priest Rapids Dam, substantive signs of GBD in fish were observed in only one sampling period. This period ended on 1 June when about 5% of resident fish sampled displayed signs of GBD. During a 5-week period prior to 1 June, levels of DGS in the areas where fish were sampled averaged from 119 to 122% of saturation, while in midriver DGS averaged 118 to 125%.

Downstream from Bonneville Dam, signs of GBD were observed in five species of fish, but the highest prevalence of GBD signs did not exceed 3% at any time; DGS rarely exceeded 120%.

For each 4-day holding test downstream from Ice Harbor Dam, signs of GBD among captive fish were observed from 24 April through 1 August, when average DGS in the pens ranged from 115 to 130% of saturation. Most signs of GBD were observed among fish held near the surface (0-0.5 m). However, some signs of GBD were observed in fish held in the deep cage and in the 0- to 4-m-deep net-pen. From 4 May through 20 June, prevalence of external signs of GBD averaged 97% for captive resident nonsalmonids and 80% for hatchery chinook salmon held in surface cages. Signs of GBD for resident nonsalmonids and hatchery chinook salmon averaged 37 and 52%, respectively, in the 0- to 4-m-deep net-pen, and 40 and 6%, respectively, in

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[1] English units used in this report due to regional convention.

the 2- to 3-m-deep cage. Resident fish used for the net-pen studies were taken from the river and often had signs of GBD at introduction to the tests. At the end of the 4-day tests, GBD signs among the captive fish often persisted and sometimes showed an increase in prevalence.

Mortality of resident nonsalmonids and hatchery chinook salmon downstream from Ice Harbor Dam was highest for fish held in the shallow cage, second highest for fish held in the 0- to 4-m-deep net-pen, and lowest for those in the deep cage. During the period from 4 May to 20 June, resident nonsalmonids and hatchery chinook salmon held in the shallow cages experienced very high mortality (58 to 100%). In the 0- to 4-m-deep net-pens during that period, resident nonsalmonids experienced 0 to 16% mortality, and salmonids experienced 1 to 84% mortality. After 23 June, average DGS dropped to about 118% of saturation, and mortality of captive fish was negligible.

Downstream from Ice Harbor Dam, prevalence of GBD in captive resident fish held 4 days in 0- to 4-m-deep net-pens was higher than in resident fish sampled in the river 1 to 7 days later. With only one exception, the prevalence of GBD signs in captive fish was about double that observed in sampled fish, even in those areas with gas levels similar to those at the 0- to 4-m net-pen location.

Downstream from Ice Harbor Dam, mortality rates of juvenile salmonids held in 0- to 4-m-deep net-pens were not representative of river migrants because of duration of exposure and depth restrictions. Salmonids were utilized in this research to provide a reference point for evaluation of resident species tolerance levels. Much field and laboratory data are documented for DGS/GBD tolerance in juvenile salmonids, but little data are available for resident fish species.

The disparity between GBD signs in the river and the net-pen negated the use of mortality data from the net-pen as a direct index of mortality in the river, even for those locations where DGS was highest. Therefore, we recommend that alternate locations for and methods of holding be explored to continue the long-term goal of developing a multiparameter model relating DGS levels (related to water flow and spill volumes) to signs of GBD and mortality of aquatic organisms.

In the Bonneville and Priest Rapids reaches, we observed low prevalence of GBD signs in sampled fish and low mortalities in captive fish during this study. However, because we did observe high prevalence of GBD signs in fish downstream from Ice Harbor Dam when saturation levels exceeded 120%, we recommend GBD monitoring whenever DGS exceeds 120%.

CONTENTS

INTRODUCTION

In recent years, high spill levels have 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 passage route through dams on the Columbia and Snake Rivers. However, increased spill has also raised concern that a subsequent increase in dissolved gas levels may be detrimental to the aquatic biota.

Supersaturation of dissolved atmospheric gases can lead to gas bubble disease (GBD), which is potentially lethal to fish and invertebrates. During spring 1993, 1994, and 1995, dissolved gas levels in the Columbia and Snake Rivers often exceeded 110% of saturation. This is the maximum level established 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 were caused by high river flows and turbine outages over which there was no control. However, some supersaturation occurred as a result of spill for fish passage.

In 1994 and 1995, a temporary variance for the 110% saturation maximum standard was obtained 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 during the period of spill. An intensified GBD monitoring program was instituted to evaluate the consequences of these actions.

Many studies on GBD and its effects on salmonids have been conducted. From 1968 to 1975, GBD in high-flow years contributed to high mortality in 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 dissolved gas, duration of exposure, water temperature, general physical condition, and swimming depth (Ebel et al. 1975). Thorough reviews of the dissolved gas supersaturation literature and 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 levels of dissolved gas supersaturation (DGS) that salmonids can safely tolerate under natural conditions.

In 1970, when it became apparent that dissolved gas supersaturation due to spill at dams was a serious problem for juvenile and adult fish in the Columbia and Snake Rivers, the U.S. Army Corps of Engineers (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 spillway flow deflectors ("flip-lips") to reduce air entrainment. As a result of these measures, there was little evidence of GBD in salmonids by the late 1970s (Dawley 1986). However, while increased turbine capacity at dams resolved the problem in part, it also increased the proportion of juvenile salmonids passing dams via turbines. Thus, passage survival at dams decreased somewhat because survival for turbine passage was less than for spillway passage (Schoeneman 1961).

The current program of increased spill was implemented in the 1980s to improve passage of downstream migrating juvenile salmonids and has resulted in diurnal fluctuations of dissolved gas levels. In 1985 and 1986, Dawley (1986) observed signs of GBD in juvenile and adult salmonids in the Columbia River at McNary, John Day, The Dalles, and Bonneville Dams. Based on low prevalence of GBD signs, he concluded that the impacts of dissolved gas supersaturation were minimal, probably because of a very short duration of high supersaturation levels.
In addition, he concluded that these high levels of gas saturation were a result of flows exceeding

hydro capacity, not of spill for fish passage.

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 were conducted 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 studies were also conducted before the development of tensiometers[2], which are capable of continuously recording dissolved gas saturation levels. The objective of this study was to assess some of the impacts of ambient levels of gas supersaturated water on aquatic organisms residing in the Columbia and Snake Rivers.

METHODS

Sampling Locations

Sampling to assess impacts of GBD in resident fish species and invertebrates was conducted in the lower Columbia River, the mid-Columbia River and the lower Snake River. In the lower Columbia River, sampling downstream from Bonneville Dam (River Kilometer (RKm) 229.1 to RKm 218.8) was conducted weekly from 20 April to 14 August 1995 (Fig. 1). In the mid-Columbia River, sampling upstream from Priest Rapids Dam in Priest Rapids Reservoir (RKm 650.5 to RKm 640.7) was conducted weekly from 13 April to 20 July 1995 (Fig. 2). In the lower Snake River, sampling downstream from Ice Harbor Dam (RKm 13.7 to RKm 1.6) was conducted weekly from 14 April to 15 August 1995 (Fig. 3).

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

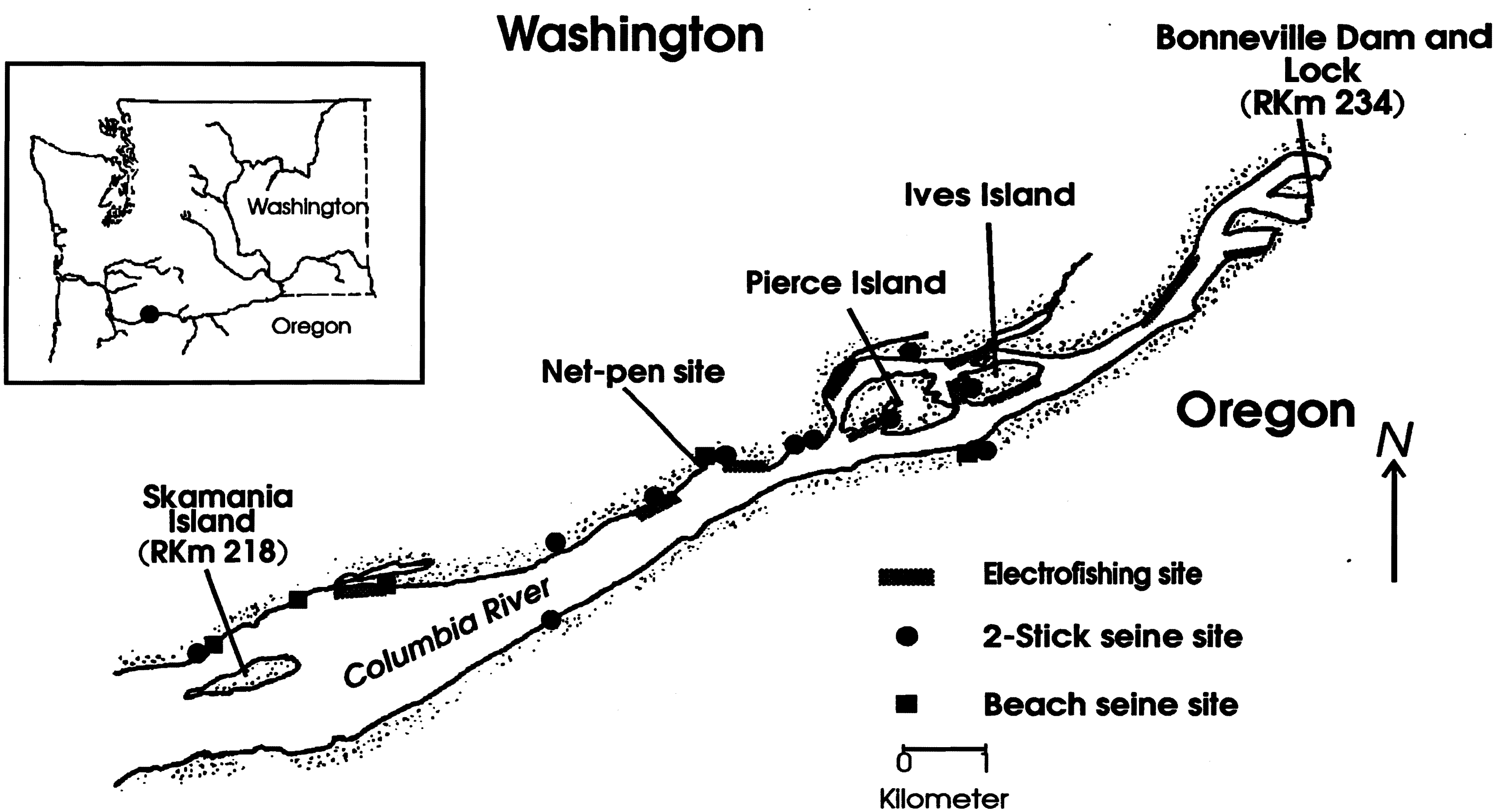

Figure 1. Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in the Columbia River downstream from Bonneville Dam, 1995.

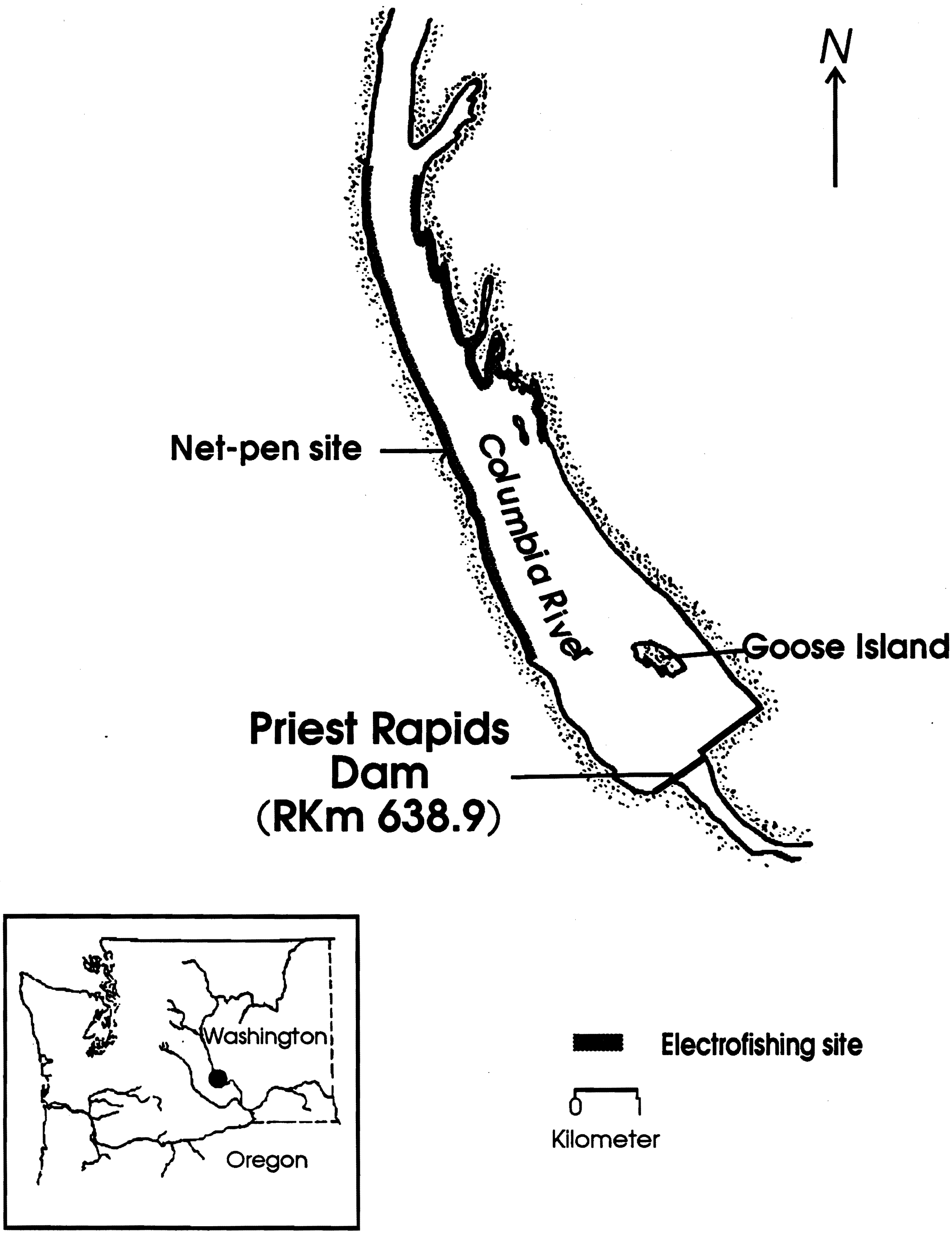

Figure 2. Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in the Columbia River at Priest Rapids Reservoir, 1995.

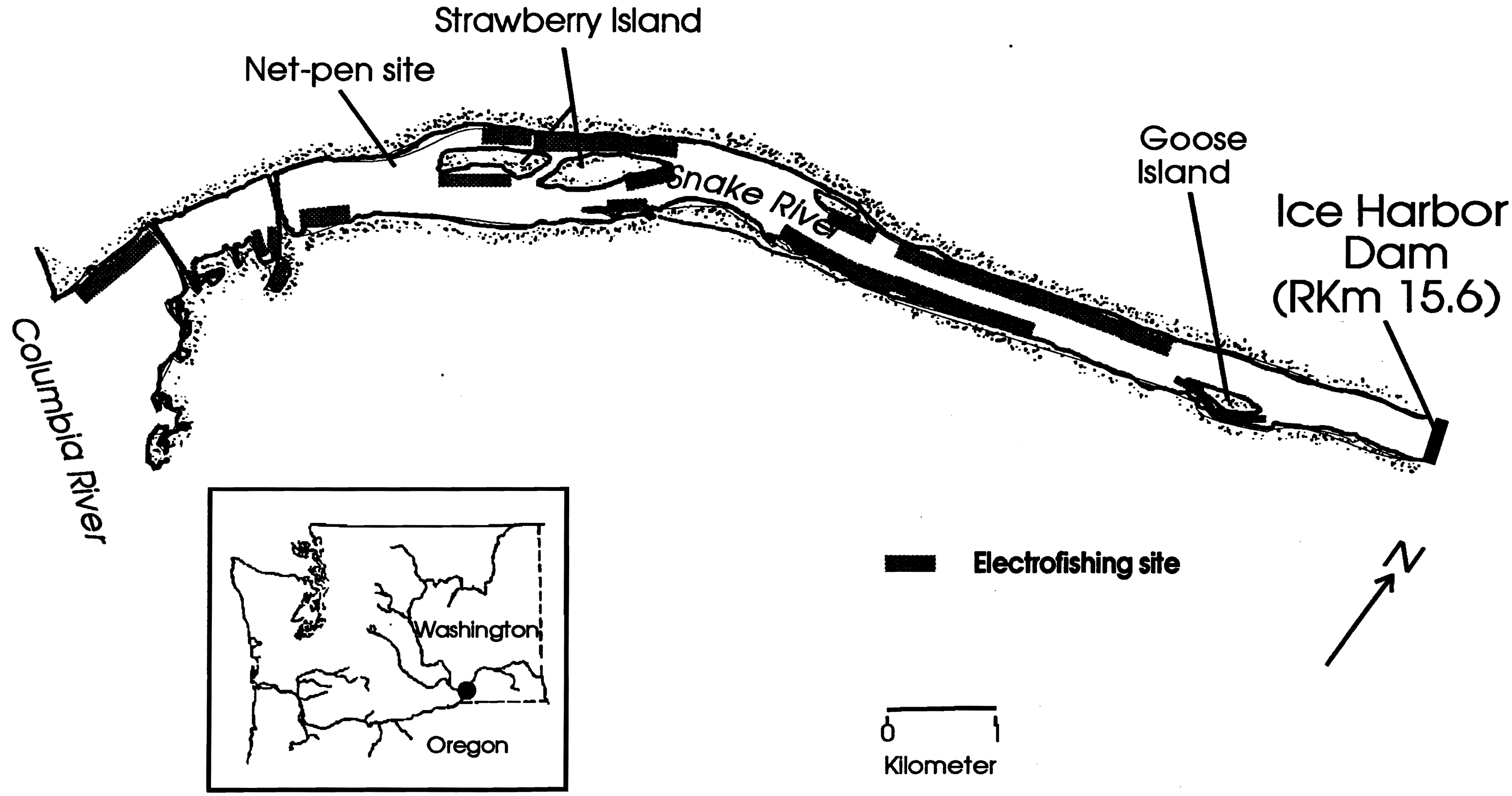

Figure 3. Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in the Snake River downstream from Ice Harbor Dam, 1995.

Sampling Methods

Up to 100 individuals of a targeted resident fish species were collected weekly from each river reach. Downstream from Bonneville Dam, the primary sampling method was electrofishing from a boat equipped with a pair of adjustable booms and fitted with umbrella anode arrays. These anode arrays consisted of six stainless steel cables, which were lowered into the water when fishing. All electrofishing used pulsed direct current at 30 pulses/second, 400-500 volts, and 1-2 amperes.

In some shallow areas, a 7.5-m 2-stick seine with 12.7-mm webbing was used to collect fish. Two people pulled the seine upstream along the beach collecting fish from no deeper than 1m. Along shorelines with a steep gradient, a 3.4-m-deep, 50-m variable-mesh beach seine was used. The beach seine consisted of panels sewn end to end. These panels included 14.0 m of 19.0-mm stretch measure, 17.1 m of 12.7-mm stretch measure, 5.5 m of 9.5-mm stretch measure, and 13.4 m of 19.0-mm stretch measure webbing. Knotless webbing was used in the beach-seine bunt to avoid descaling fish. To deploy the net, we anchored one end of the seine in dry sand and set the net in a wide arc with a 5-m outboard-powered boat, returning to the beach at an upstream point.

All fish were anesthetized, identified, measured to the nearest millimeter, and examined for external injuries and signs of GBD (subcutaneous emphysema on fins, head, eyes, and body surface). Up to 100 individuals of each species were examined using a 2.5 to 5-power headband magnifying lens. Internal examinations of anesthetized live resident nonsalmonids were not conducted.

Most examinations were made within 15 minutes of collection at the sampling site. During the examination period, 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.

Benthic and epibenthic invertebrates were collected weekly at several locations below Bonneville and Ice Harbor Dams. These samples were collected from depths of up to 0.6 m using either a 0.6-m-diameter plankton net with 0.5-mm mesh, an epibenthic pump, or a Ponar bottom sampler. Samples of epifauna that encrusted aquatic vegetation were also collected. Samples collected with the epibenthic pump, Ponar bottom samplers, and samples from aquatic vegetation were washed through a 0.5-mm screen, and all invertebrates were retained. Most organisms were examined within 15 minutes of collection using a dissecting microscope with 15- to 40-power magnification.

Nebeker et al. (1976) and White et al. (1991) documented the occurrence of both internal and external bubbles in aquatic invertebrates. Increased buoyancy of the organisms, resulting from the presence of gas bubbles, could result in involuntary drift and greater sensitivity to dissolved gas supersaturation. We believe that external gas bubbles may have formed as a result of our sampling procedures, so we documented only observations of internal gas bubbles.

Net-pen Studies

Weekly observations of survival and changes in prevalence of GBD were made for resident nonsalmonid species and invertebrates. Specimens were collected, examined for prevalence of GBD, held in net-pens and cages for 4 days, and then reexamined for prevalence of GBD. Hatchery-reared subyearling fall chinook salmon (*O. tshawytscha*) obtained from Bonneville Hatchery were also held in net-pens at two sites: downstream from Bonneville Dam and downstream from Ice Harbor Dam.

Three types of net-pens were used: shallow, perforated aluminum-plate cages (0.6 x 0.6 x 1.0 m held at the surface and providing a maximum depth of 0.5 m); deep, submerged perforated aluminum-plate cages (0.6 x 0.6 x 1.0 m held at depths from 2.0 to 3.0 m); and large, variable-depth net-pens (1.8 x 2.44 m) with a net partition extending from the bottom to above the water surface and running the entire length of the net. Fish over 140 mm were placed on one side of the partition, while hatchery chinook salmon and resident fish under 140 mm were placed on the other side to help reduce intra-pen predation. Fish in net-pens had access to a water column from the surface to a depth of 4 m. Up to 100 individuals of each species were held in these pens. Invertebrates were held in a vertically positioned, 7.6-cm diameter, 155-cm-long PVC tube with 2.6-cm-diameter holes arranged around the tube wall. These holes were covered with 0.1-mm mesh to prevent escapement while allowing water circulation.

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 10 to 25 hatchery chinook salmon were examined more closely for gas bubbles in the lateral line, brachial arteries, and gill lamellae, using a dissecting microscope with 15-power magnification. All resident fish mortalities were examined for internal signs of GBD. Mortalities in moderate to extreme states of decomposition were not examined. Invertebrates were reexamined using the same procedure utilized during sampling.

Dissolved Gas Measurements

Total dissolved gas concentrations were measured at the time of sampling at each location and at the net-pens using tensiometers. We measured dissolved gas concentrations at 4-hour increments during net-pen holding experiments. Means and ranges of DGS during 4-day holding periods were determined from 4-hour data records.

Additional dissolved gas data were accessed from the Columbia River Operations Hydromet System (CROHMS) data network maintained by the North Pacific Division of the COE.

Data Analysis

Linear and non-linear regression were used to evaluate correlation of GBD signs to mortality from results of the 0- to 4-m-deep holding experiments downstream from Ice Harbor Dam. Because mortality sometimes occurred as a result of high temperatures, severe turbulence, and latent handling effects, as well as GBD, only data with positive GBD signs were included in this analysis. An arcsine transformation was used to normalize percentage data.

Analysis of variance was used to evaluate difference in prevalence of GBD signs between captive and free-swimming resident species.

RESULTS

GBD in Fish and Invertebrate Samples

Downstream from Bonneville Dam

Downstream from Bonneville Dam, 127 salmonids, 1,936 nonsalmonids, and 804 invertebrates were collected for a total of 21 species of fish and 12 taxa of invertebrates (Tables 1 and 2). Among all fish sampled and examined, only resident nonsalmonids exhibited external signs of GBD; these comprised 0.1% of the total. Signs of GBD were seen from early to late June when the highest DGS at sampling sites were measured (Table 3, Fig. 4). Lateral line examinations were performed on 223 of the fish sampled, with 3.8% displaying signs of GBD in the lateral line (Table 4). Both salmonids and nonsalmonids displayed lateral line signs of GBD with the greatest prevalence of GBD occurring in June.

Table 1. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Columbia River downstream from Bonneville Dam, 20 April to 14 August, 1995.

Species	Scientific name	Sample (n)	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Peamouth	*Mylocheilus courinus*	756	31-406	0	
Largescale sucker	*Catastomus macrocheilus*	385	112-679	0	
Northern squawfish	*Ptychocheilus oregonensis*	254	61-744	0	
Stickleback	*Gasterosteus aculeatus*	194	26-119	1	0.6
Crappie	*Pomozis spp.*	92	40-148	0	
Redside shiner	*Richardsonius balteatus*	92	41-219	0	
Chinook salmon	*Oncorynchus tshawytscha*	120	56-108	0	
Pumpkinseed	*Lepomis gibbosus*	40	49-151	0	
Sculpin	*Cottus spp.*	39	31-154	1	2.7
Carp	*Cyprinus carpio*	20	227-650	0	
Smallmouth bass	*Micropterus dolomieui*	20	30-400	0	
Goldfish	*Carassius auratus*	14	132-300	0	
Yellow perch	*Perca flavescens*	9	111-233	0	
Chiselmouth	*Acrocheilus alutaceus*	4	50-303	0	
Walleye	*Stizistedion vitreum vitreum*	4	250-470	0	
Coho salmon	*Oncorynchus kisutch*	5	92-145	0	
Unidentified fish		4	21[c]	0	
American shad	*Alosa sapidissima*	3	340-391	0	
Largemouth bass	*Micropterus salmoides*	3	90-444	0	
Brown bullhead	*Ictalurus nebulosus*	2	192-201	0	
Steelhead trout	*Salmo gairdneri*	2	116-222	0	
Speckled dace	*Rhinichthys osculus*	1	104	0	
Total salmonids		127		0	0
Total non-salmonids		1936		2	0.1

[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 - 5.0 power headband magnifying lens.

[c] Only one unidentified fish was measured.

Table 2. Numbers sampled and prevalence of gas bubble disease by taxa for invertebrates collected from the Snake and Columbia Rivers, 1995.

	Downstream from Bonneville Dam 26 April to 8 August			Downstream from Ice Harbor Da 14 April to 9 August		
	Sample	GBD prevalence*		Sample	GBD prevalence*	
Taxa	(n)	(n)	(%)	(n)	(n)	(%)
Amphipoda	141	0	0	9	0	0
Argulus	0	0	0	1	0	0
Bryozoa	0	0	0	1	0	0
Chironomidea	237	0	0	146	0	0
Cladocera	211	1	0.5	57	2	3.5
Pelecypoda	0	0	0	5	0	0
Coleoptera	0	0	0	1	0	0
Copepoda	35	0	0	72	0	0
Corophium	69	0	0	0	0	0
Culicidae	0	0	0	5	0	0
Diptera Adult	0	0	0	0	0	0
Dolichopodidae larvae	0	0	0	9	0	0
Muscidae larvae	0	0	0	4	0	0
Gastropoda	2	0	0	3	0	0
Hydracarina	91	0	0	87	0	0
Insect larvae (unidentified)	5	0	0	0	0	0
Mysid	2	0	0	0	0	0
Nemeatoda	2	0	0	1	0	0
Oligochaeta	9	0	0	93	0	0
Pupa (unidentified)	0	0	0	2	0	0
Total invertebrates	804	1	0.1	499	2	0.4

* Examinations for signs of GBD were completed using a dissecting microscope with 10 to 40-power magnification.

Table 3. Prevalence of GBD in resident fish[a] and dissolved gas levels[b] for sampling in the lower Columbia River, 1995

Downstream from Bonneville Dam

		Prevalence of GBD by severity[c] Percent of fin area with emphysema							
	sample	0 - 10	11 - 25	26 - 50	>50% or with body, eye, head emphysema	Prevalence of GBD		% TDG at sampling sites	
Date	(n)	(n)	(n)	(n)	(n)	(n)	(%)	Avg.	Range
Apr-20	31	0	0	0	0	0	0.0	106	104.6-106.5
Apr-24	78	0	0	0	0	0	0.0	104	100.7-109.7
Apr-27	17	0	0	0	0	0	0.0	116	114.2-116.9
Apr-28	8	0	0	0	0	0	0.0	115	114.7-114.7
May-4	50	0	0	0	0	0	0.0	113	102.5-116.4
May-5	132	0	0	0	0	0	0.0	115	114.0-115.6
May-12	164	0	0	0	0	0	0.0	116	114.2-118.4
May-18	67	0	0	0	0	0	0.0	113	110.5-113.7
May-19	72	0	0	0	0	0	0.0	114	113.4-115.2
May-25	224	0	0	0	0	0	0.0	117	115.6-117.8
Jun-1	138	0	0	0	0	0	0.0	117	114.2-117.7
Jun-8	144	1	0	0	0	1	0.7	115	112.6-117.2
Jun-14	40	0	0	0	0	0	0.0	118	116.5-118.5
Jun-15	87	0	0	0	0	0	0.0	116	115.7-116.4
Jun-22	37	0	0	0	0	0	0.0	114	113.0-114.9
Jun-23	35	0	0	0	0	0	0.0	114	114.0-114.8
Jun-29	163	1	0	0	0	1	0.6	115	113.4-115.7
Jun-30	36	0	0	0	0	0	0.0	114	110.1-116.8
Jul-6	145	0	0	0	0	0	0.0	108	107.6-109.0
Jul-7	40	0	0	0	0	0	0.0	111	108.5-113.5
Jul-13	130	0	0	0	0	0	0.0	111	108.1-113.0
Jul-20	146	0	0	0	0	0	0.0	111	109.6-114.5
Jul-27	255	0	0	0	0	0	0.0	115	112.3-117.9
Aug-3	227	0	0	0	0	0	0.0	116	110.8-120.0
Aug-4	232	0	0	0	0	0	0.0	116	115.3-117.0
Aug-8	108	0	0	0	0	0	0.0	117	115.7-119.5
Aug-14	80	0	0	0	0	0	0.0	118	117.9-118.0

[a] Resident fish include all species of fish captured on the Columbia River.

[b] Mean and range of total dissolved gas levels (% of saturation) measured at sampling sites at the time of sampling.

[c] Prevalence of GBD segregated by severity. Individuals were categorized by the most severe sign observed (emphysema covering more than 50% of a fin was considered equivalent to emphysema on other parts of the body).

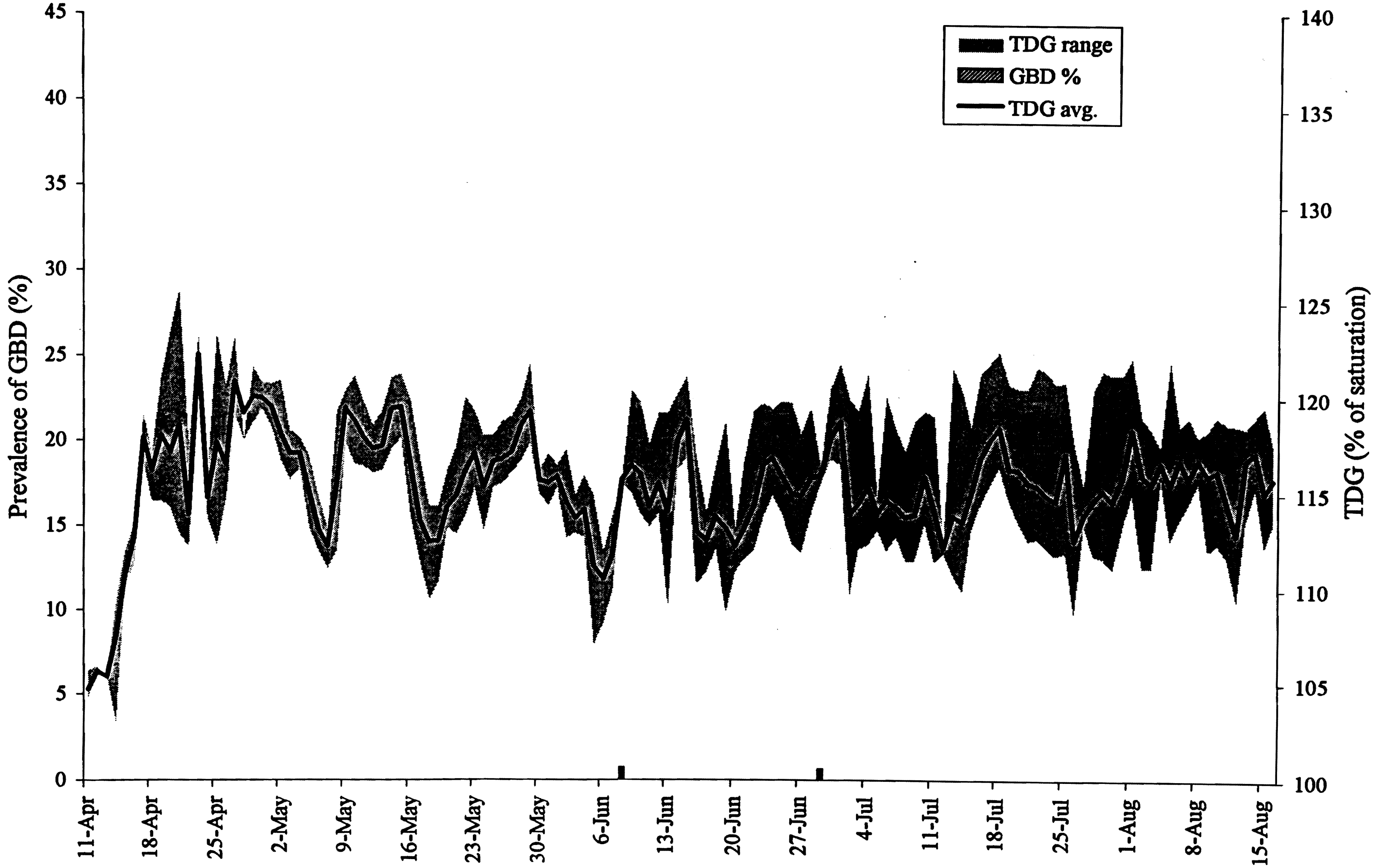

Figure 4. Prevalence of GBD in resident fish collected in weekly samples from the Columbia River downstream from Bonneville Dam compared with daily average and range of TDG (total dissolved gas).

Table 4. Results of examinations for gas emboli in the lateral line[a] of resident fish collected downstream from Bonneville Dam, 1995.

	Apr-20		Jun-14		Jun-23		Jun-30		Jul-7		Aug-4		Aug-8		Aug-14		Total examined	
		GBD		GBD		GBD		GBD		GBD		GBD		GBD		GBD		GBD
Species		(%)[c]	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Chinook salmon	3	0.0	-	-	-	-	-	-	8	0.0	-	-	-	-	-	-	11	0.0
Steelhead trout	1	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.0
Coho salmon	-	-	-	-	-	-	-	-	1	0.0	-	-	-	-	-	-	1	0.0
Peamouth	-	-	10	20.0	7	0.0	10	0.0	3	33.3	9	0.0	4	50.0	10	0.0	53	9.4
Redside shiner	-	-	-	-	-	-	1	0.0	1	0.0	-	-	-	-	-	-	2	0.0
Northern squawfish	-	-	3	66.6	3	0.0	6	33.3	4	0.0	-	-	1	0.0	-	-	17	23.5
Crappie	-	-	-	-	-	-	-	-	16	0.0	11	0.0	-	-	-	-	27	0.0
Largescale sucker	-	-	17	11.8	17	29.4	15	6.7	-	-	-	-	-	-	1	0.0	50	16.0
Smallmouth bass	-	-	-	-	1	0.0	-	-	1	0.0	-	-	-	-	-	-	2	0.0
Stickleback	-	-	-	-	1	0.0	-	-	1	0.0	10	0.0	27	0.0	19	10.5	58	3.4
Pumpkinseed	-	-	-	-	1	0.0	-	-	-	-	-	-	-	-	-	-	1	0.0
Total for period	4	0.0	30	20.0	30	16.6	32	9.4	35	2.9	30	0.0	32	6.3	30	6.7		
																Total	223	8.5

[a] Examinations for signs of GBD were completed using a dissecting microscope with 10 to 40-power magnification.

[b] Number of fish examined for GBD signs in the lateral line.

[c] Percent of examined fish displaying gas emboli in the lateral line.

Signs of GBD were observed in one resident nonsalmonid on both 8 and 29 June. On those days, respective midriver DGS averaged 115.7 and 116.4% and peaked at 117.9 and 120.0%. On the same dates, respective DGS averaged 114.9 and 114.1% at the sampling sites. Levels of DGS at shallow-water sampling sites, where many fish and invertebrates reside, were most often less than midriver levels.

Throughout the study period, fish species displaying GBD signs were sculpin (*Cottus spp.*, 2.7%) and three-spine stickleback (*Gasterosteus aculeatus*, 0.6%). These GBD signs manifested themselves as subcutaneous emphysema between rays of the pectoral fins covering less than 10% of the fin surface. Of the invertebrates sampled, only cladocera showed signs of GBD and only at a minimal prevalence (0.5%, Table 2).

Priest Rapids Reservoir

In Priest Rapids Reservoir, a total of 16 taxa comprised of 1 hatchery steelhead and 2,511 resident nonsalmonids were collected (Table 5). Invertebrates were not collected in this area.

Spill at Wanapum Dam caused high DGS in Priest Rapids Reservoir (up to 124.2% of saturation in midriver and 123.7% at resident sampling sites) during May and early June (Table 6 and Fig. 5). Signs of GBD were observed in 1.4, 0.8, 0.4, 5.4 and 0.6% of resident nonsalmonids collected on 2, 5, and 12 May and 1 and 15 June, respectively. Throughout the study period, fish species displaying signs of GBD were sandroller (*Percopsis transmontana*, 5.6%), sculpin (*Cottus spp.*, 4.8%), smallmouth bass (*Micropterus dolomieui*, 1.6%), pumpkinseed (*Lepomis gibbosus*, 0.6%), northern squawfish (*Ptychocheilus oregonensis*, 0.2%), and redside shiner (*Richardsonius balteatus*, 0.1%) (Table 5).

External signs of GBD varied among species, but the most common were subcutaneous emphysema in the dorsal, caudal, and pectoral fins. Occurrences (particularly in sculpin) of severe

Table 5. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Columbia River upstream from Priest Rapids Dam, 13 April to 20 July 1995.

Species	Scientific name	(n)	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Redside shiner	*Richardsonius balteatus*	759	42-154	1	0.1
Northern squawfish	*Ptychocheilus oregonensis*	503	45-482	1	0.2
Sculpin	*Cottus spp.*	331	52-220	16	4.8
Largescale sucker	*Catastomus macrocheilus*	312	52-541	0	
Pumpkinseed	*Lepomis gibbosus*	162	47-161	1	0.6
Bluegill	*Lepomis macrochirus*	126	43-160	0	
Chiselmouth	*Acrocheilus alutaceus*	65	61-257	0	
Smallmouth bass	*Micropterus dolomieui*	63	58-386	1	1.6
Yellow perch	*Perca flavescens*	59	61-143	0	
Peamouth	*Mylocheilus courinus*	51	54-190	0	
Stickleback	*Gasterosteus aculeatus*	39	47-92	0	
Sandroller	*Percopsis transmontana*	36	50-116	2	5.6
Carp	*Cyprinus carpio*	2	187-332	0	
Largemouth bass	*Micropterus salmoides*	2	38-157	0	
Crappie	*Pomozis spp.*	1	109	0	
Steelhead	*Salmo giardneri*	1	217	0	
Total salmonids		1		0	0
Total non-salmonids		2511		22	0.9

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

[b] External examination for sighs of GBD using a 2.5 - 5.0 power headband magnifying lens.

Table 6. Prevalence of GBD in resident fish[a] and dissolved gas levels[b] for sampling in the mid-Columbia River, 1995

Priest Rapids Reservoir

Date	sample (n)	Prevalence of GBD by severity[c] Percent of fin area with emphysema: 0 - 10 (n)	11 - 25 (n)	26 - 50 (n)	>50% or with body, eye, head emphysema (n)	Prevalence of GBD (n)	Prevalence of GBD (%)	% TDG at sampling sites Avg.	% TDG at sampling sites Range
Apr-13	12	0	0	0	0	0	0.0	109	107.0-110.4
May-2	73	1	0	0	0	1	1.4	122	118.8-124.0
May-5	262	2	0	0	0	2	0.8	119	118.6-119.8
May-12	282	1	0	0	0	1	0.4	117	115.0-119.0[d]
May-19	228	0	0	0	0	0	0.0	119	118.7-120.0
May-25	249	0	0	0	0	0	0.0	122	118.9-124.2
Jun-1	299	9	1	3	7	16	5.4	121	118.3-123.7
Jun-8	145	0	0	0	0	0	0.0	107	103.9-109.7
Jun-15	175	0	0	0	1	1	0.6	110	107.8-111.4
Jun-22	152	0	0	0	0	0	0.0	110	109.2-110.7
Jun-29	178	0	0	0	0	0	0.0	112	109.3-115.0
Jul-6	167	0	0	0	0	0	0.0	110	109.1-110.0
Jul-13	191	0	0	0	0	0	0.0	114	113.5-115.3
Jul-20	148	0	0	0	0	0	0.0	108	106.6-108.6

[a] Resident fish include all species of fish captured on the Columbia River.

[b] Mean and range of total dissolved gas levels (% of saturation) measured at sampling sites at the time of sampling.

[c] Prevalence of GBD segregated by severity. Individuals were categorized by the most severe sign observed; where by emphysema covering more than 50% of a fin was considered equivalent to emphysema on other parts of the body.

[d] Measured at Dam, not at sampling sites.

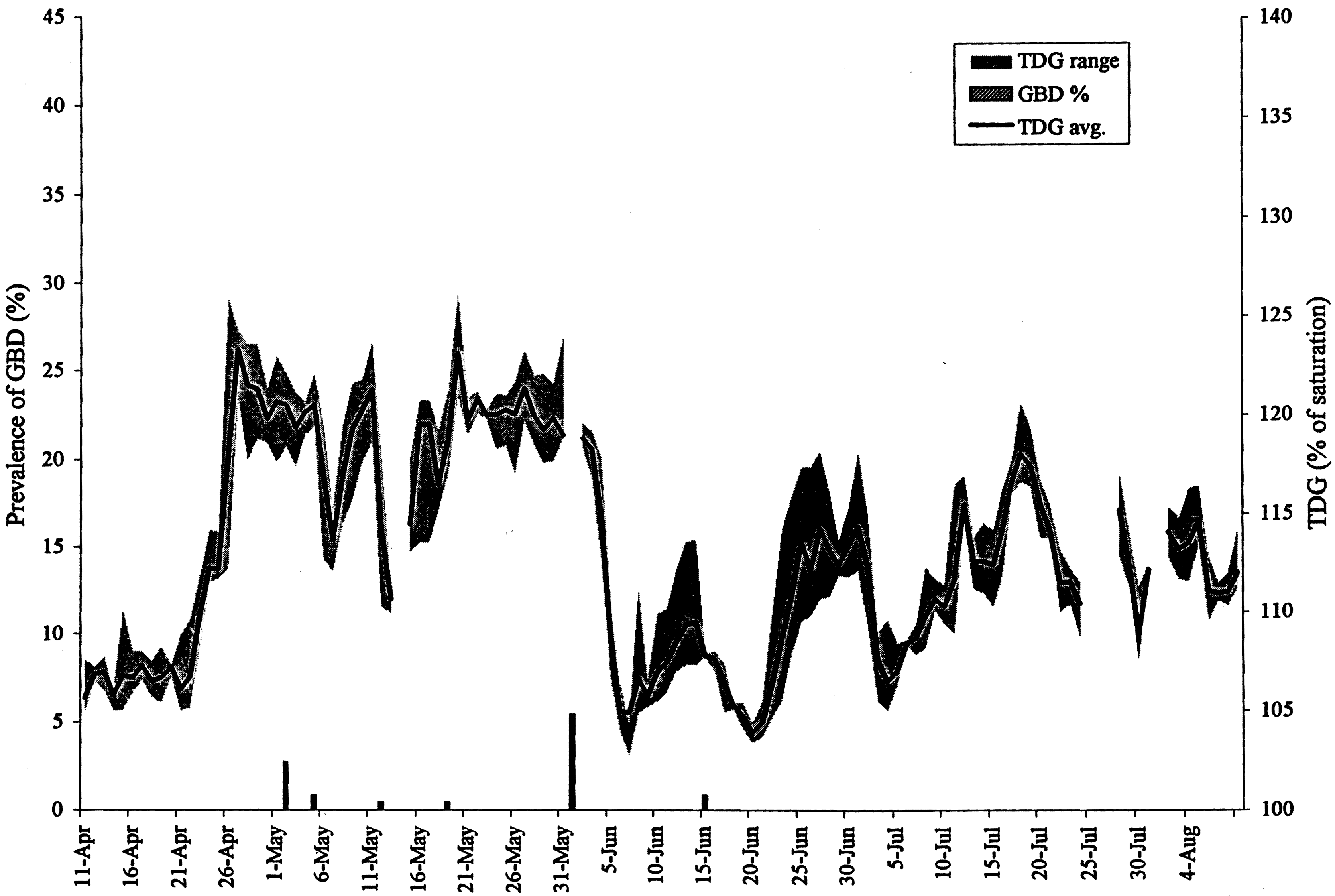

Figure 5. Prevalence of GBD in resident fish collected in weekly samples from the Columbia River in Priest Rapids Reservoir compared with daily average and range of TDG (total dissolved gas).

signs of subcutaneous emphysema on the mid-ventral body surface and head were also observed on 1 and 15 June (Table 6 and Fig. 5).

Downstream from Ice Harbor Dam

Downstream from Ice Harbor Dam, a total of 18 taxa of invertabrates and 16 species of fish comprised of 2 salmonids, 2,823 nonsalmonids, and 499 invertebrates were collected (Tables 2 and 7). Overall prevalence of GBD for fish examined throughout the 14 April through 15 August sampling season was 9.0% (Table 7). In all but 4 (chinook salmon, chiselmouth, carp, and sandrollers)of the 16 species of fish sampled, at least one individual displayed external signs of GBD. Three fish species showed external signs of GBD in over 10% of their respective sample populations: smallmouth bass (*Micropterus dolomieui*, 16.5%), crappie (*Pomozis spp*., 13.6%), and brown bullhead catfish (*Ictalurus nebulosus*, 11.8%).

Between 4 May and 20 June, DGS was extremely high as a result of turbine outages; spill as high as 76,700 ft^3/sec and 52.7% of total river flow occurred because of the limited turbine capacity. DGS during this period reached 138.5% of saturation in midriver on 7 May. DGS reached 134.6% of saturation at a resident fish sampling site on 16 May (Table 8 and Fig. 6). Signs of GBD were observed in 20% of resident fish captured during this time, and nearly half of these displayed severe GBD signs. Prevalence of GBD signs reached a high of 40.8% in the sample collected on 9 May (Table 8 and Fig. 6). Two of the 499 invertebrates collected below Ice Harbor Dam showed signs of GBD.

Table 7. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Snake River downstream from Ice Harbor Dam, 14 April to 15 August 1995.

Species	Scientific name	(n)	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Smallmouth bass	*Micropterus dolomieui*	885	26-670	146	16.5
Peamouth	*Mylocheilus caurinus*	477	82-303	12	2.5
Sculpin	*Cottus spp.*	566	40-178	32	5.7
Largescale sucker	*Catastomus macrocheilus*	268	60-567	26	9.7
Yellow perch	*Perca flavescens*	186	76-218	10	5.4
Northern squawfish	*Ptychocheilus oregonensis*	140	65-206	7	5.0
Largemouth bass	*Micropterus salmoides*	86	48-443	5	5.8
Bluegill	*Lepomis macrochirus*	76	44-185	7	9.2
Crappie	*Pomozis spp.*	44	42-235	6	13.6
Chiselmouth	*Acrocheilus alutaceus*	32	126-259	0	
Pumpkinseed	*Lepomis gibbosus*	21	65-114	1	4.8
Brown bullhead	*Ictalurus nebulosus*	17	43-222	2	11.8
Redside shiner	*Richardsonius balteatus*	12	68-133	1	8.3
Carp	*Cyprinus carpio*	11	94-654	0	
Sandroller	*Percopsis transmontana*	2	76-99	0	
Chinook salmon	*Oncorhynchus tshawytscha*	2	45-55	0	
Total salmonids		2		0	0.0
Total non-salmonids		2823		255	9.0

[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 - 5.0 power headband magnifying lens.

Table 8. Prevalence of GBD in resident fish[a] and dissolved gas levels[b] for sampling in the lower Snake River, 1995

Downstream from Ice Harbor Dam

Date	sample (n)	Prevalence of GBD by severity[c] Percent of fin area with emphysema: 0 - 10 (n)	11 - 25 (n)	26 - 50 (n)	>50% or with body, eye, head emphysema (n)	Prevalence of GBD (n)	Prevalence of GBD (%)	% TDG at sampling sites Avg.	Range
Apr-14	16	1	0	0	0	1	6.3	105.3	104.8-105.8
Apr-19	90	0	0	0	0	0	0	112.3	108.5-115.5
Apr-24	205	1	0	0	0	1	0.5	112.8	111.4-114.2
May-4	57	1	1	0	0	2	3.5	116.8	100.0-125.8
May-8	37	1	0	0	0	1	2.7	119.5	119.0-121.6
May-9	130	21	2	1	33	53	40.8	119.9	116.9-120.0
May-11	46	6	0	0	2	7	15.2	120.1	118.8-122.3
May-18	147	15	1	0	6	21	14.3	123.4	121.3-127.2
May-26	207	33	0	0	30	55	26.6	125.9	117.5-130.8
Jun-2	200	26	0	0	6	30	15.0	131.6	130.6-132.7
Jun-9	227	25	1	1	23	46	20.3	129.3	126.4-132.2
Jun-16	169	9	0	0	12	18	10.7	128.1	111.7-134.6
Jun-23	204	7	0	0	14	17	8.3	112.8	109.0-115.3
Jun-30	175	4	0	1	4	7	4.0	114.5	113.1-115.9
Jul-7	177	0	0	0	0	0	0.0	110.4	109.1-111.6
Jul-14	171	0	0	0	0	0	0.0	112.3	108.7-118.9
Jul-21	90	0	0	0	0	0	0.0	106.2	105.0-107.3
Jul-28	115	0	0	0	2	2	1.7	111.4	107.0-114.4
Aug-2	134	0	0	0	1	1	0.7	107.2	101.5-110.3
Aug-10	74	0	0	0	0	0	0.0	114.4	112.1-116.3
Aug-15	90	0	0	0	0	0	0.0	118.0	103.9-111.5

[a] Resident fish include all species of fish captured on the Snake River.

[b] Mean and range of total dissolved gas levels (% of saturation) measured at sampling sites at the time of sampling.

[c] Prevalence of GBD segregated by severity. Individuals were categorized by the most severe sign observed (emphysema covering more than 50% of a fin was considered equivalent to emphysema on other parts of the body).

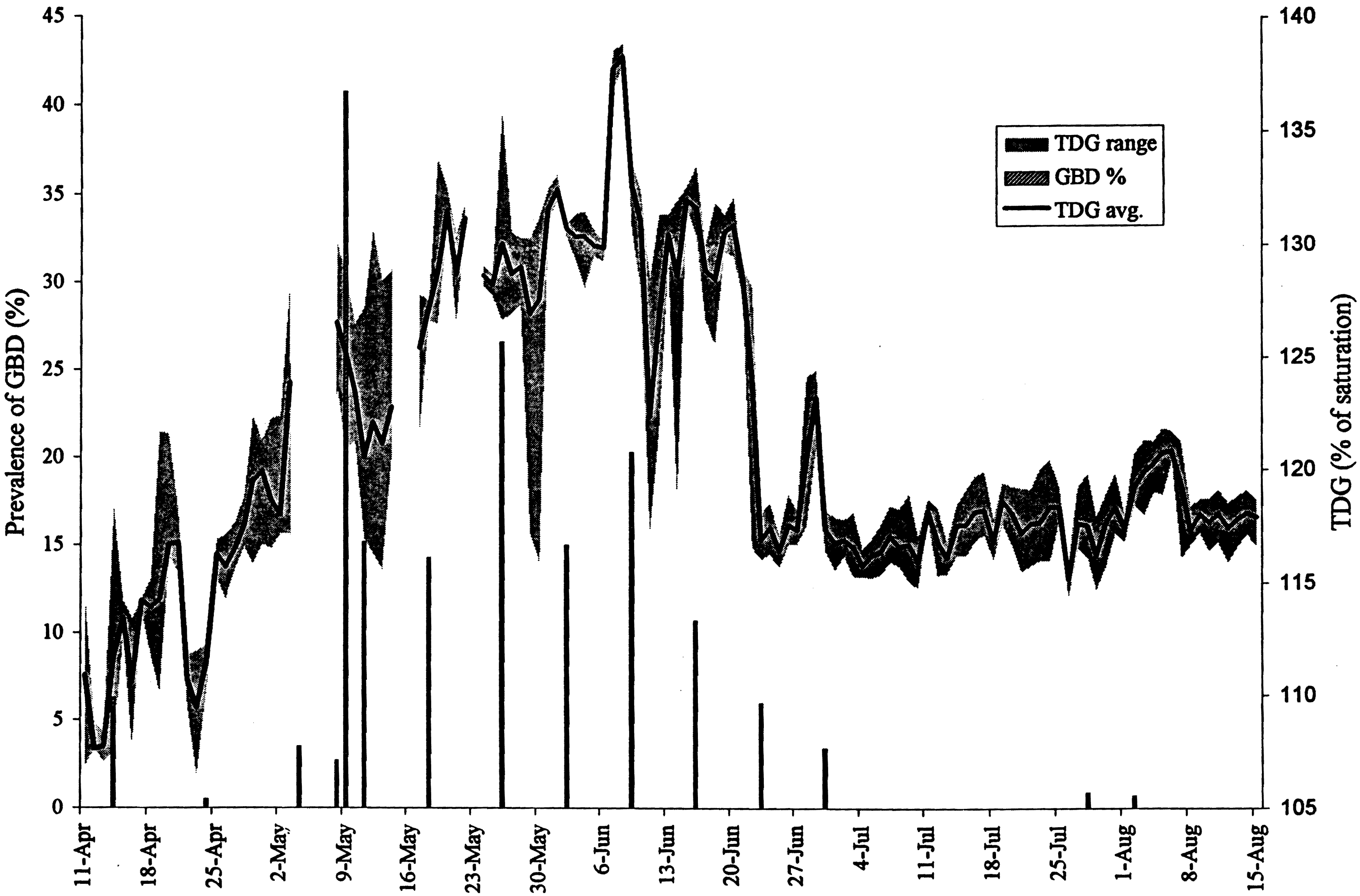

Figure 6. Prevalence of GBD in resident fish collected in weekly samples from the Snake River downstream from Ice Harbor Dam compared with daily average and range of TDG (total dissolved gas).

GBD in Captive Fish Groups

Downstream from Bonneville Dam

Results of net-pen holding experiments conducted downstream from Bonneville Dam with resident fish and hatchery chinook salmon are summarized in Tables 9 and 10, respectively. Some signs of GBD were observed among hatchery chinook salmon in all 13 4-day holding periods from 4 May through 1 August, when average daily DGS in the pens ranged from 113 to 118% of saturation. Resident nonsalmonids were held during 15 4-day periods from 20 April through 31 July, when average DGS in the pens ranged from 113 to 120% of saturation. Most signs of GBD were observed among fish held near the surface (0-0.5 m). However, some signs were observed among fish held in the deep cage (2-3 m) and in the 0- to 4-m-deep net-pen.

Signs of GBD in hatchery salmon (up to 90%) were primarily emboli in the lateral lines while subcutaneous emphysema between fin rays was observed less frequently (up to 80%). The highest prevalence of subcutaneous emphysema was observed in samples taken from 14 through 18 July, when gas levels peaked at 122.4% of saturation (Table 10).

Hatchery salmon appeared less resistant to high DGS than other fishes. Salmon held in surface cages generally had a higher prevalence of subcutaneous emphysema in fins than resident fish, even though the resident fish had previous exposure to dissolved gas prior to the 4 days of holding. Some mortalities occurred but were unrelated to signs of GBD and levels of DGS. These mortalities were thought to be a consequence of shifting water currents and rough water conditions, which at times caused the net-pen and cages to bounce violently.

No signs of GBD were observed in the invertebrates that were held in the cage over any 4-day period.

Table 9. Gas bubble disease in resident fish[a] (non-salmonids) held 4-days in river water[b] downstream from Bonneville Dam, 1995.

	Introduction		Termination											
			Survivors examined					Mortalities examined						
								external		LL		gill		
Date/		GBD		GBD	Mortality		Decay		GBD		GBD		GBD	
Conditions	(n)[c]	(%)[d]	(n)[e]	(%)[f]	(n)[g]	(%)	(n)[h]	(n)[i]	(%)[j]	(n)[k]	(%)[l]	(n)[m]	(%)[n]	
April 20-24					**TDG 117% (112.2-125.7%)**									
surface	7	0.0	6	0.0	0	0.0	--	--	--	--	--	--	--	
0-4 m	12	0.0	12	16.7	0	0.0	--	--	--	--	--	--	--	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	
April 27-May 2					**TDG 120% (116.7-123.2%)**									
surface	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	
0-4 m	0	--	--	--	--	--	--	--	--	--	--	--	--	
deep	15	0.0	14	0.0	0	0.0	--	--	--	--	--	--	--	
May 4-9					**TDG 115% (111.1-120.4%)**									
surface	0	--	--	--	--	--	--	--	--	--	--	--	--	
0-4 m	152	0.0	135	0.0	7	4.9	0	7	0.0	0	--	0	--	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	
May 12-16					**TDG 118% (113.7-121.2%)**									
surface	14	0.0	16	18.8	0	0.0	--	--	--	--	--	--	--	
0-4 m	103	0.0	80	1.3	1	1.2	0	1	0.0	0	--	0	--	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	
May 18-23					**TDG 115% (109.4-120.0%)**									
surface	0	--	--	--	--	--	--	--	--	--	--	--	--	
0-4 m	136	0.0	110	0.0	0	0.0	--	--	--	--	--	--	--	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	
May 25-30					**TDG 117% (115.0-121.8%)**									
surface	31	0.0	1[o]	100.0	0	0.0	--	--	--	--	--	--	--	
0-4 m	98	0.0	93	0.0	2	2.1	0	2	50.0	2	100.0	2	0.0	
deep	8	0.0	7	0.0	1	12.5	0	1	0.0	0	--	0	--	
June 1-6					**TDG 113% (107.0-117.3%)**									
surface	16	0.0	15	6.7	0	0.0	--	--	--	--	--	--	--	
0-4 m	89	0.0	82	0.0	2	2.4	0	2	0.0	2	0.0	2	0.0	
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	
June 8-12					**TDG 116% (113.3-120.4%)**									
surface	26	0.0	24	12.5	0	0.0	--	--	--	--	--	--	--	
0-4 m	82	0.0	72	0.0	2	2.7	0	2	0.0	2	0.0	2	0.0	
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	
June 15-19					**TDG 114% (108.7-121.1%)**									
surface	6	0.0	6	33.3	0	0.0	--	--	--	--	--	--	--	
0-4 m	59	0.0	46	0.0	6	11.5	1	5	0.0	5	20.0	5	0.0	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	

Table 9. continued.

Date/ Conditions	Introduction (n)[c]	Introduction GBD (%)[d]	Termination: Survivors examined (n)[e]	Survivors examined GBD (%)[f]	Mortality (n)[g]	Mortality (%)	Decay (n)[h]	Mortalities examined: external (n)[i]	external GBD (%)[j]	LL (n)[k]	LL GBD (%)[l]	gill (n)[m]	gill GBD (%)[n]
June 22-26					**TDG 116% (112.0-119.8%)**								
surface	8	0.0	7	28.6	0	0.0	--	--	--	--	--	--	--
0-4 m	30	0.0	28	0.0	1	3.4	1	0	--	0	--	0	--
deep	4	0.0	4	0.0	0	0.0	--	--	--	--	--	--	--
June 29July 3					**TDG 116% (109.7-121.8%)**								
surface	26	3.8	23	4.3	3	11.5	0	3	33.3	3	0.0	3	0.0
0-4 m	94	0.0	80	0.0	6	7.0	3	3	0.0	3	0.0	3	0.0
deep	10	0.0	3	0.0	1	25.0	1	0	--	0	--	0	--
July 6-10					**TDG 114% (111.5-120.0%)**								
surface	24	0.0	22	13.6	3	12.0	0	3	0.0	3	33.3	2	0.0
0-4 m	64	0.0	57	0.0	0	0.0	--	--	--	--	--	--	--
deep	11	0.0	7	0.0	0	0.0	--	--	--	--	--	--	--
July 13-17					**TDG 115% (109.8-121.8%)**								
surface	26	0.0	19	5.3	7	26.9	3	4	0.0	4	0.0	4	0.0
0-4 m	47	0.0	42	0.0	1	2.3	1	0	--	0	--	0	--
deep	13	0.0	5	0.0	1	16.7	0	1	0.0	0	--	0	--
July 20-24					**TDG 115% (111.7-121.6%)**								
surface	34	0.0	25	8.0	6	19.4	2	4	0.0	4	25.0	4	0.0
0-4 m	68	0.0	57	0.0	11	16.2	3	8	0.0	8	0.0	8	0.0
deep	16	0.0	11	0.0	5	31.3	2	3	0.0	3	0.0	3	0.0
July 27-31[p]					**TDG 115% (111.0-121.4%)**								
surface	50	0.0	33	3.0	12	26.7	3	9	33.3	9	22.2	7	0.0
0-4 m	96	0.0	11	0.0	53	82.8	9	44	0.0	11	0.0	11	0.0
deep	35	0.0	11	0.0	1	8.3	0	1	0.0	1	0.0	1	0.0

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 1).
[b] Dissolved gas measured inside 0-4 m net-pen.
[c] Number of fish placed in each pen at the beginning of the experiment.
[d] Percent of fish with external signs of GBD at beginning of experiment.
[e] Number of fish alive on day 4 of the experiment.
[f] Percent of surviving fish with external signs of GBD.
[g] Number of mortalities on day 4 of the experiment.
[h] Number of mortalities that were too decomposed to observe for GBD signs on day 4.
[i] Number of mortalities examined for external signs of GBD.
[j] Percent of examined mortalities displaying external signs of GBD.
[k] Number of mortalities examined for GBD signs in the lateral line.
[l] Percent of examined mortalities displaying GBD signs in the lateral line.
[m] Number of mortalities examined for GBD signs in the gills.
[n] Percent of examined mortalities displaying GBD signs in the brachial arteries or gill lamellae.
[o] All but one fish escaped from the surface pen due to equipment failure.
[p] Five day holding period.

Table 10. Gas bubble disease in hatchery reared subyearling fall chinook salmon[a] held 4-days in river water downstream from Bonneville Dam, 1995.

	Survivors examined									Mortalities examined					
	external		LL		gill					external		LL		gill	
		GBD		GBD		GBD	Mortality		Decay		GBD		GBD		GBD
Date/ Conditions	(n)[c]	(%)[d]	(n)[e]	(%)[f]	(n)[g]	(%)[h]	(n)[i]	(%)	(n)[j]	(n)[k]	(%)[l]	(n)[m]	(%)[n]	(n)[o]	(%)[p]
May 4-9						**TDG 115% (111.1-120.4%)**									
surface	10	0.0	10	30.0	0	--	0	0.0	--	--	--	--	--	--	--
0-4 m	59	0.0	15	0.0	0	--	7	10.6	0	7	0.0	0	--	0	--
deep	10	0.0	10	20.0	0	--	0	0.0	--	--	--	--	--	--	--
May 11-15						**TDG 118% (116.1-121.1%)**									
surface	23	17.4	10	90.0	0	--	0	0.0	--	--	--	--	--	--	--
0-4 m	47	2.1	10	50.0	0	--	0	0.0	--	--	--	--	--	--	--
deep	23	0.0	12	58.3	0	--	0	0.0	--	--	--	--	--	--	--
May 18-22						**TDG 114% (109.4-120.0%)**									
surface	24	8.3	14	57.1	14	0.0	1	4.0	0	1	0.0	1	0.0	1	0.0
0-4 m	46	4.4	12	25.0	23	0.0	2	4.2	0	2	0.0	0	--	0	--
deep	25	0.0	10	80.0	13	0.0	0	0.0	--	--	--	--	--	--	--
May 26-30						**TDG 118% (115.0-121.8%)**									
surface	25	44.0	21	71.4	21	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	51	9.8	13	23.1	13	0.0	6	10.5	1	5	0.0	4	25.0	4	0.0
deep	10	0.0	10	20.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 2-6						**TDG 113% (107.0-117.3%)**									
surface	25	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	33	0.0	11	9.1	11	0.0	54	62.1	52	2	0.0	1	0.0	1	0.0
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 9-13						**TDG 115% (109.0-120.4%)**									
surface	26	23.1	20	35.0	20	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	78	1.3	11	9.1	11	0.0	36	31.6	14	22	0.0	0	--	0	--
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 16-20						**TDG 113% (108.7-118.8%)**									
surface	19	21.1	16	43.8	16	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	41	2.4	11	18.2	11	0.0	36	46.8	26	10	0.0	10	0.0	10	0.0
deep	10	0.0	10	10.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 23-27						**TDG 116% (111.9-119.8%)**									
surface	25	40.0	20	75.0	20	5.0	0	0.0	--	--	--	--	--	--	--
0-4 m	39	7.7	13	30.8	13	0.0	1	2.5	0	1	0.0	1	0.0	1	0.0
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 30-Jul 4						**TDG 116% (109.7-121.8%)**									
surface	25	36.0	18	16.7	18	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	59	1.7	10	20.0	10	0.0	3	4.8	3	0	--	0	--	0	--
deep	10	0.0	10	10.0	10	0.0	0	0.0	--	--	--	--	--	--	--

Table 10. Continued.

	Survivors examined									Mortalities examined					
	external		LL		gill					external		LL		gill	
Date/		GBD		GBD		GBD	Mortality		Decay		GBD		GBD		GBD
Conditions	(n)[c]	(%)[d]	(n)[e]	(%)[f]	(n)[g]	(%)[h]	(n)[i]	(%)	(n)[j]	(n)[k]	(%)[l]	(n)[m]	(%)[n]	(n)[o]	(%)[p]
July 7-11						**TDG 114% (111.4-119.3%)**									
surface	23	39.1	19	21.1	19	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	55	1.8	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
deep	9	0.0	9	0.0	9	0.0	0	0.0	--	--	--	--	--	--	--
July 14-18						**TDG 116% (109.8-122.4%)**									
surface	25	80.0	17	70.6	17	5.9	0	0.0	--	--	--	--	--	--	--
0-4 m	62	3.2	12	8.3	12	0.0	0	0.0	--	--	--	--	--	--	--
deep	11	0.0	11	0.0	11	0.0	0	0.0	--	--	--	--	--	--	--
July 21-25						**TDG 116% (111.7-121.6%)**									
surface	25	24.0	16	18.8	16	0.0	0	0.0	--	--	--	--	--	--	--
0-4 m	69	0.0	11	0.0	11	0.0	1	1.4	1	0	--	0	--	0	--
deep	10	0.0	10	20.0	10	0.0	0	0.0	--	--	--	--	--	--	--
Jul 28-Aug 1						**TDG 116% (111.0-122.1%)**									
surface	24	29.2	16	31.3	16	0.0	2	7.7	0	2	0.0	2	0.0	2	0.0
0-4 m	121	0.8	13	0.0	13	0.0	12	9.0	6	6	0.0	6	0.0	6	0.0
deep	10	0.0	10	10.0	10	0.0	0	0.0	--	--	--	--	--	--	--

[a] Fork length range; 50 to 125 mm.

[b] Dissolved gas measured inside 0-4 m net-pen.

[c] Number of fish alive on day 4 of the experiment.

[d] Percent of survivors with external signs of GBD.

[e] Number of survivors examined for GBD signs in the lateral line.

[f] Percent of examined survivors displaying GBD signs in the lateral line.

[g] Number of survivors examined for GBD signs in the gills.

[h] Percent of examined survivors displaying GBD signs in the brachial arteries or gill lamellae.

[i] Number of mortalities on day 4 of the experiment.

[j] Number of mortalities that were too decomposed to observe for GBD signs on day 4.

[k] Number of mortalities examined for external signs of GBD.

[l] Percent of examined mortalities displaying external signs of GBD.

[m] Number of mortalities examined for GBD signs in the lateral line.

[n] Percent of examined mortalities displaying GBD signs in the lateral line.

[o] Number of mortalities examined for GBD signs in the gills.

[p] Percent of examined mortalities displaying GBD signs in the brachial arteries or gill lamellae.

Priest Rapids Reservoir

Results of net-pen holding experiments with resident nonsalmonids conducted in Priest Rapids Reservoir are summarized in Table 11. Due to the theft of our net-pen support barge and the attached cage-holding gear, we could not conduct experiments with the shallow or deep cages until new gear had been designed, built, and put in place for use starting 1 June. Signs of GBD were observed during five holding experiments concluding on 9 May, 23 May, 30 May, 5 June, and 26 June; however, no mortality attributed to GBD was observed.

Prevalence of subcutaneous emphysema between fin rays of resident fish ranged from 4 to 20.0% for those held in the surface cage and from 0 to 5.3% for those held in the 0- to 4-m-deep net-pen. Weekly dissolved gas levels averaged from 106 to 121% of saturation. No fish from the deep pen displayed GBD signs during the entire testing period.

Downstream from Ice Harbor Dam

Results of net-pen holding experiments conducted downstream from Ice Harbor Dam are summarized for resident fish and hatchery chinook salmon in Tables 12 and 13, respectively.

The highest prevalence of GBD signs was observed during holding experiments conducted from 4 May to 20 June, when weekly average DGS measured in the pens ranged from 122 to 130%. Signs of GBD (subcutaneous emphysema) for resident nonsalmonids and hatchery chinook salmon averaged 97 and 80%, respectively, in the surface cages; 37 and 52%, respectively, in the 0- to 4-m-deep net-pen; and 40 and 6%, respectively, in the 2- to 3-m-deep cage. However, resident fish used for the net-pen studies were taken from the river and often had signs of GBD at introduction to the tests.

At the end of the 4-day tests, GBD signs among the captive fish often persisted and sometimes showed an increase in prevalence. Due to equipment problems, data from deep cage

Table 11. Gas bubble disease in resident fish[a] (non-salmonids) held 4-days in river water[b] in Priest Rapids Reservoir, 1995.

	Introduction		Termination										
			Survivors examined					Mortalities examined					
								external		LL		gill	
Date/ Conditions	(n)[c]	GBD (%)[d]	(n)[e]	GBD (%)[f]	Mortality (n)[g]	Mortality (%)	Decay (n)[h]	(n)[i]	GBD (%)[j]	(n)[k]	GBD (%)[l]	(n)[m]	GBD (%)[n]
May 5-9					**TDG 118% (112.1-122.1%)**								
surface	0	--	0	--	0	0.0	--	--	--	--	--	--	--
0-4m	262	0.8	213	0.5	9	4.1	0	9	0.0	0	--	0	--
deep	0	--	0	--	0	0.0	--	--	--	--	--	--	--
May 12-16					**TDG 115% (109.9-120.8%)**								
surface	0	--	0	--	0	0.0	--	--	--	--	--	--	--
0-4m	282	0.4	189	--	12	6.0	7	5	0.0	0	--	0	--
deep	0	--	0	--	0	0.0	--	--	--	--	--	--	--
May 19-23					**TDG 121% (117.1-126.2%)**								
surface	0	--	0	--	0	0.0	--	--	--	--	--	--	--
0-4m	225	0.4	160	3.1	26	14.0	11	15	0.0	0	--	15	0.0
deep	0	--	0	--	0	0.0	--	--	--	--	--	--	--
May 26-30					**TDG 120% (117.1-123.3%)**								
surface	0	--	0	--	0	0.0	--	--	--	--	--	--	--
0-4m	248	0.0	171	5.3	23	11.9	20	3	0.0	0	--	0	--
deep	0	--	0	--	0	0.0	--	--	--	--	--	--	--
June 1-5					**TDG 115% (106.6-119.6%)**								
surface	25	0.0	23	20.0	0	0.0	--	--	--	--	--	--	--
0-4m	264	6.1	206	0.0	22	9.6	21	1	0.0	0	--	1	0.0
deep	10	0.0	7	0.0	9	56.3	2	7	0.0	0	--	0	--
June 8-12					**TDG 107% (104.9-112.2%)**								
surface	26	0.0	23	0.0	2	8.0	2	0	--	0	--	0	--
0-4m	109	0.0	92	0.0	12	11.5	5	7	0.0	3	0.0	3	0.0
deep	10	0.0	7	0.0	3	30.0	3	0	--	0	--	0	--
June15-19					**TDG 106% (104.1-108.0%)**								
surface	25	0.0	25	0.0	0	0.0	--	--	--	--	--	--	--
0-4m	85	1.2	59	0.0	9	13.2	4	5	0.0	0	--	0	--
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 22-26					**TDG 110% (104.7-117.4%)**								
surface	25	0.0	25	4.0	0	0.0	--	--	--	--	--	--	--
0-4m	111	0.0	91	0.0	7	7.1	7	0	--	0	--	0	--
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
Jun 29-Jul 3					**TDG 112% (105.5-118.1%)**								
surface	25	0.0	24	0.0	2	7.7	2	0	--	0	--	0	--
0-4m	116	--	0[o]	--	--	0.0	--	--	--	--	--	--	--
deep	10	0.0	9	0.0	0	0.0	--	--	--	--	--	--	--

Table 11. Continued.

	Introduction		Termination											
			Survivors examined					Mortalities examined						
								external		LL		gill		
Date/ Conditions	(n)[c]	GBD (%)[d]	(n)[e]	GBD (%)[f]	Mortality (n)[g]	Mortality (%)	Decay (n)[h]	(n)[i]	GBD (%)[j]	(n)[k]	GBD (%)[l]	(n)[m]	GBD (%)[n]	
July 6-10					**TDG 110% (1107.8-112.3%)**									
surface	25	0.0	20	0.0	5	20.0	1	4	0.0	2	0.0	3	0.0	
0-4m	125	0.0	82	0.0	35	29.9	24	11	0.0	12	0.0	12	0.0	
deep	10	0.0	4	0.0	5	55.6	5	0	--	0	--	0	--	
July 13-17					**TDG 114% (110.3-117.7%)**									
surface	29	0.0	6	0.0	13	68.4	11	2	0.0	2	0.0	2	0.0	
0-4m	144	0.0	121	0.0	18	12.9	16	2	0.0	2	0.0	2	0.0	
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	
July 20-24					**TDG 113% (108.8-116.7%)**									
surface	25	0.0	6	0.0	12	66.7	9	3	0.0	3	0.0	2	0.0	
0-4m	108	0.0	83	0.0	15	15.3	12	3	0.0	3	0.0	3	0.0	
deep	10	0.0	4	0.0	6	60.0	6	0	--	0	--	0	--	

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 4).
[b] Dissolved gas measured inside 0-4 m net-pen.
[c] Number of fish placed in each pen at the beginning of the experiment.
[d] Percent of fish with external signs of GBD at beginning of experiment.
[e] Number of fish alive on day 4 of the experiment.
[f] Percent of surviving fish with external signs of GBD.
[g] Number of mortalities on day 4 of the experiment.
[h] Number of mortalities that were too decomposed to observe for GBD signs on day 4.
[i] Number of mortalities examined for external signs of GBD.
[j] Percent of examined mortalities displaying external signs of GBD.
[k] Number of mortalities examined for GBD signs in the lateral line.
[l] Percent of examined mortalities displaying GBD signs in the lateral line.
[m] Number of mortalities examined for GBD signs in the gills.
[n] Percent of examined mortalities displaying GBD signs in the brachial arteries or gill lamellae.
[o] Due to boat emergency, fish were released before examinations could be conducted.

Table 12. Gas bubble disease in resident fish[a] (non-salmonids) held 4-days in river water[b] downstream from Ice Harbor Dam, 1995.

	Introduction		Termination											
			Survivors examined					Mortalities examined						
								external		LL		gill		
Date/ Conditions	(n)[c]	GBD (%)[d]	(n)[e]	GBD (%)[f]	Mortality (n)[g]	Mortality (%)	Decay (n)[h]	(n)[i]	GBD (%)[j]	(n)[k]	GBD (%)[l]	(n)[m]	GBD (%)[n]	
April 24-28	**15% (110.2-1**													
surface	25	0.0	25	24.0	0	0.0	--	--	--	--	--	--	--	
0-4 m	75	0.0	67	0.0	1	1.5	0	1	0.0	0	--	0	--	
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	
May 4-8					**TDG 126% (123.7-130.2%)**									
surface	25	4.0	6	83.3	19	76.0	0	19	94.7	0	--	--	--	
0-4 m	32	3.1	26	3.8	0	0.0	--	--	--	--	--	--	--	
deep	0	--	--	--	--	--	--	--	--	--	--	--	--	
May 11-15					**TDG 122% (115.6-130.7%)**									
surface	0	--	--	--	--	--	No fish introduced to cage this week							
0-4 m	38	10.5	32	18.8	6	15.8	0	6	100.0	0	--	0	--	
deep	0	--	--	--	--	--	No fish introduced to cage this week							
May 18-22					**TDG 130% (126.5-133.8%)**									
surface	25	20.0	4	75.0	21	84.0	0	21	100.0	21	61.9	21	14.3	
0-4 m	112	13.4	98	41.8	8	7.5	0	8	88.0	5	40.0	5	20.0	
deep	10	10.0	0	--	--	Control fish lost due to a faulty latch.								
May 26-30					**TDG 128% (115.9-135.9%)**									
surface	25	40.0	1	100.0	24	96.0	0	24	100.0	22	63.6	22	0.0	
0-4 m	171	24.0	124	37.9	19	13.3	3	16	93.8	17	11.8	19	5.3	
deep	10	40.0	9	55.6	1	10.0	0	1	100.0	1	0.0	1	0.0	
June 2-6					**TDG 130% (128.1-131.5%)**									
surface	11	9.1	4	100.0	7	63.6	0	7	100.0	5	80.0	4	0.0	
0-4 m	141	14.2	128	43.0	14	9.9	4	10	70.0	9	33.3	9	11.1	
deep	24	12.5	23	17.4	1	4.2	1	0	--	0	--	0	--	
June 9-13					**TDG 129% (117.3-133.6%)**									
surface	25	8.0	6	100.0	19	76.0	0	19	100.0	15	66.7	19	0.0	
0-4 m	189	19.6	168	21.4	9	5.1	2	7	71.4	7	0.0	7	0.0	
deep	10	40.0	6	50.0	0	0.0	--	--	--	--	--	--	--	
June 16-20					**TDG 130% (125.6-133.5%)**									
surface	25	4.0	5	80.0	20	80.0	5	15	100.0	15	33.3	15	6.7	
0-4 m	123	10.6	101	36.6	13	11.4	9	4	75.0	2	50.0	2	0.0	
deep[o]	10	30.0	7	57.1	3	30.0	1	2	100.0	2	50.0	2	0.0	
June 23-27					**TDG 117% (115.7-118.9%)**									
surface	25	0.0	4	25.0	0	0.0	Four fish were recovered.							
0-4 m	162	9.9	144	3.5	5	3.4	4	1	0.0	1	0.0	1	0.0	
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--	

Table 12. Continued.

	Introduction		Termination											
			Survivors examined					Mortalities examined						
								external		LL		gill		
Date/ Conditions	(n)[c]	GBD (%)[d]	(n)[e]	GBD (%)[f]	Mortality (n)[g]	Mortality (%)	Decay (n)[h]	(n)[i]	GBD (%)[j]	(n)[k]	GBD (%)[l]	(n)[m]	GBD (%)[n]
Jun 30-Jul 4					**TDG 117% (115.3-118.2%)**								
surface	26	0.0	0	--	A support broke allowing the fish to escape								
0-4 m	122	3.3	105	1.9	4	3.7	4	0	--	0	--	0	--
deep	11	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
July 7-11					**TDG 117% (114.8-118.9%)**								
surface	25	0.0	21	0.0	1	4.5	0	1	0.0	1	0.0	1	0.0
0-4 m	138	0.0	125	0.0	9	6.7	8	1	0.0	1	0.0	1	0.0
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
July 14-18					**TDG 118% (116.0-119.9%)**								
surface	25	0.0	23	8.7	0	0.0	--	--	--	--	--	--	--
0-4 m	131	0.0	112	0.9	2	1.8	2	0	--	0	--	0	--
deep	10	0.0	9	0.0	1	10.0	0	1	0.0	1	0.0	1	0.0
July 21-25					**TDG 118% (115.5-120.4%)**								
surface	25	0.0	20	5.0	5	20.0	2	3	0.0	3	0.0	3	0.0
0-4 m	50	0.0	33	0.0	13	28.3	11	2	0.0	2	0.0	2	0.0
deep	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
July 28-Aug					**TDG 117% (114.7-119.8%)**								
surface	26	0.0	25	16.0	0	0.0	--	--	--	--	--	--	--
0-4 m	77	1.3	59	0.0	8	11.9	8	0	--	0	--	0	--
deep	10	0.0	9	0.0	0	0.0	--	--	--	--	--	--	--

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 5).
[b] Dissolved gas measured inside 0-4 m net-pen.
[c] Number of fish placed in each pen at the beginning of the experiment.
[d] Percent of fish with external signs of GBD.
[e] Number of fish alive on day 4 of the experiment.
[f] Percent of surviving fish with external signs of GBD.
[g] Number of mortalities on day 4 of the experiment.
[h] Number of mortalities that were too decomposed to observe for GBD signs on day 4.
[i] Number of mortalities examined for external signs of GBD.
[j] Percent of examined mortalities displaying external signs of GBD.
[k] Number of mortalities examined for GBD signs in the lateral line.
[l] Percent of examined mortalities displaying GBD signs in the lateral line.
[m] Number of mortalities examined for GBD signs in the gills.
[n] Percent of examined mortalities displaying GBD signs in the brachial arteries or gill lamellae.
[o] Cage attachment severed which caused shallow depth orientation; not used for analysis.

Table 13. Gas bubble disease in hatchery reared subyearling fall chinook salmon[a] held 4-days in river water[b] downstream from Ice Harbor Dam, 1995.

Date/ Conditions	Survivors examined: external (n)[c]	external GBD (%)[d]	LL (n)[e]	LL GBD (%)[f]	gill (n)[g]	gill GBD (%)[h]	Mortality (n)[i]	Mortality (%)	Decay (n)[j]	Mortalities examined: external (n)[k]	external GBD (%)[l]	LL (n)[m]	LL GBD (%)[n]	gill (n)[o]	gill GBD (%)[p]
May 4-8							**TDG 126% (123.7-130.4%)**								
Surface	0	--	0	--	0	--	24	100.0	0	24	54.2	11	27.3	0	--
0-4m	9	22.2	5	100.0	0	--	47	83.9	1	46	19.6	5	40.0	0	--
deep	1	0.0	1	0.0	0	--	9	90.0	0	9	33.3	9	0.0	0	--
May 9-13							**TDG 122% (115.6-130.7%)**								
Surface	4	25.0	4	100.0	4	0.0	23	85.2	0	23	65.2	5	40.0	4	0.0
0-4m	23	47.8	5	20.0	23	0.0	37	61.7	1	36	13.9	5	20.0	5	0.0
deep	5	20.0	5	60.0	5	0.0	5	50.0	0	5	40.0	2	0.0	2	0.0
May 11-15							**TDG 122% (115.6-130.7%)**								
Surface	10	40.0	5	100.0	5	0.0	14	58.3	--	14	92.9	5	60	5	0.0
0-4m	68	29.4	10	40.0	10	0.0	1	1.4	1	--	--	--	--	--	--
deep	0	--	0	--	0	--	--	--	--	--	--	--	--	--	--
May 18-22							**TDG 130% (126.5-133.8%)**								
Surface	3	0.0	3	100.0	3	33.3	23	88.5	0	23	95.7	23	0.0	23	13.0
0-4m	46	56.5	10	40.0	10	0.0	12	20.7	1	11	100.0	10	50	10	0.0
deep	0	Deep cage fish lost due to a faulty latch.													
May 26-30							**TDG 128% (115.9-135.9%)**								
Surface	0	--	0	--	0	--	25	100.0	1	24	95.8	24	8.3	24	16.7
0-4m	61	42.6	20	10.0	20	0.0	0	0.0	--	--	--	--	--	--	--
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 2-6							**TDG 130% (128.1-131.5%)**								
Surface	1	100.0	1	100.0	1	0.0	10	90.9	2	8	100.0	8	62.5	8	0.0
0-4m	54	63.0	20	5.0	20	5.0	5	8.5	2	3	33.3	2	0.0	2	0.0
deep	23	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
June 9-13							**TDG 128% (117.3-133.4%)**								
Surface	3	100.0	3	100.0	3	33.3	21	87.5	1	20	100.0	20	20	20	15.0
0-4m	29	72.4	18	16.7	18	22.2	38	56.7	6	32	87.5	28	0.0	26	26.9
deep	9	11.1	9	11.1	9	0.0	1	10.0	0	1	0.0	1	0.0	1	0.0
June 16-20							**TDG 130% (125.6-133.5%)**								
Surface	0	--	0	--	0	--	25	100.0	11	14	92.9	11	36.4	11	27.3
0-4m	55	85.4	18	50.0	18	38.9	8	12.7	3	5	100.0	5	60	5	40.0
deep[r]	10	70.0	10	100.0	10	0.0	0	0.0	0	0	--	0	--	0	--
June 23-27							**TDG 117% (115.7-118.9%)**								
Surface	25	20.0	25	60.0	25	0.0	0	0.0	--	--	--	--	--	--	--
0-4m	52	1.9	11	0.0	11	0.0	1	1.9	1	0	--	0	--	0	--
deep	10	0.0	10	10.0	10	0.0	0	0.0	--	--	--	--	--	--	--

Table 13. Continued.

	Survivors examined									Mortalities examined					
	external		LL		gill					external		LL		gill	
		GBD		GBD		GBD	Mortality		Decay[j]		GBD		GBD		GBD
Date/ Conditions	(n)[c]	(%)[d]	(n)[e]	(%)[f]	(n)[g]	(%)[h]	(n)[i]	(%)	(n)[k]	(n)[l]	(%)[m]	(n)[n]	(%)[o]	(n)[p]	(%)[q]
Jun 30-Jul 4[q]							**TDG 117% (115.3-118.2%)**								
Surface	25	32.0	0	--	0	--	0	0.0	0	--	--	--	--	--	--
0-4m	61	0.0	0	--	0	--	0	0.0	0	--	--	--	--	--	--
deep	10	10.0	0	--	0	--	0	0.0	0	--	--	--	--	--	--
July 7-11							**TDG 117% (114.8-118.9%)**								
Surface	21	61.9	21	19.0	21	0.0	4	16.0	4	0	--	0	--	0	--
0-4m	51	0.0	10	10.0	10	0.0	5	8.9	0	5	0.0	5	0.0	5	0.0
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
July 14-18							**TDG 118% (116.0-119.9%)**								
Surface	25	76.0	25	76.0	25	0.0	0	0.0	--	--	--	--	--	--	--
0-4m	80	1.3	11	0.0	11	0.0	0	0.0	--	--	--	--	--	--	--
deep	10	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
July 21-25							**TDG118% (115.5-120.4%)**								
Surface	27	63.0	27	37.0	27	3.7	0	0.0	--	--	--	--	--	--	--
0-4m	67	0.0	10	0.0	10	0.0	0	0.0	--	--	--	--	--	--	--
deep	8	0.0	8	0.0	8	0.0	2	20.0	2	0	--	0	--	0	--
July 28-Aug 1							**TDG 117% (114.7-119.8%)**								
Surface	15	53.3	15	6.7	15	13.3	12	44.4	12	0	--	0	--	0	--
0-4m	53	0.0	10	10.0	10	0.0	92	63.4	90	2	0.0	2	0.0	2	0.0
deep	3	0.0	3	33.3	3	0.0	7	70.0	7	0	--	0	--	0	--

[a] Fork length range: 50 to 125 mm.
[b] Dissolved gas measured inside 0-4 m net-pen.
[c] Number of fish alive on day 4 of the experiment.
[d] Percent of survivors with external signs of GBD.
[e] Number of survivors examined for GBD signs in the lateral line.
[f] Percent of examined survivors displaying GBD signs in the lateral line.
[g] Number of survivors examined for GBD signs in the gills.
[h] Percent of examined survivors displaying GBD signs in the brachial arteries or gill lamellae.
[i] Number of mortalities on day 4 of the experiment.
[j] Number of mortalities that were too decomposed to observe for GBD signs on day 4.
[k] Number of mortalities examined for external signs of GBD.
[l] Percent of examined mortalities displaying external signs of GBD.
[m] Number of mortalities examined for GBD signs in the lateral line.
[n] Percent of examined mortalities displaying GBD signs in the lateral line.
[o] Number of mortalities examined for GBD signs in the gills.
[p] Percent of examined mortalities displaying GBD signs in the brachial arteries or gill lamellae.
[q] No lateral line or gill examinations were performed on hatchery chinook for this period.
[r] Cage attachment severed which caused a shallow depth orientation; not used for analysis.

holding tests 4-8 May, 11-15 May, 18-22 May, and 16-20 June were unusable.

Gas emboli in lateral lines were observed on 100% of hatchery salmon from the surface cage in five of the tests from 9 May to 13 June. Prevalence of gas emboli in lateral lines among captive resident fish in surface cages ranged from 0 to 100%.

Resident fish held 4 days generally displayed lower prevalence of GBD than salmon even though they had previous exposure to supersaturated conditions in the river and the salmon had none.

No signs of GBD were observed in invertebrates held in the cage over any 4-day period.

Mortality among captive resident nonsalmonid and hatchery chinook salmon was higher for fish held in the shallow cage than for fish held in the 0- to 4-m net-pen and deep cage. From 4 May to 20 June, resident nonsalmonids (64% to 96%) and hatchery chinook salmon (58% to 100%) held in the shallow cage sustained high mortalities. After 23 June, average DGS dropped to near 118%, and little if any mortality occurred that could be attributed to GBD.

GBD Signs Related to Mortality

The correlations between external GBD signs in surviving fish and the percentage of mortalities for captive resident species and salmonids were positive (increased prevalence of signs relating to increased mortality), but not very strong, ($R = 0.61$ for resident fish and $R = 0.36$ for salmonids; data shown in Tables 9-13). However, these data are based on limited sample numbers at two extremes of the spectrum (high DGS and low DGS). We feel that further evaluation is necessary for our multiple year model to eliminate the possibility of artifacts due to small sample size or abnormal distribution.

To assess whether mortality from GBD in captive fish was the same as in their free-swimming counterparts, we compared the prevalence of GBD signs among those groups. Only fish sampled at sites where DGS was high--similar to DGS at the net-pen--were used for comparison. Results showed that prevalence of external signs of GBD was generally greater in captive fish than in fish collected from the Ice Harbor Reach 1 to 7 days later (Fig. 7), (probability of no difference, P = 0.33, using analysis of variance). With only one exception, prevalence of GBD signs in captive fish (0- to 4-m-deep net-pens) was about double that observed in sampled fish (Table 14), even along the north side of the river and around the islands where DGS was the highest (Fig. 2). The mortality rates observed in these holding tests were likely greater than those observed in resident fish downstream from Ice Harbor Dam, and therefore would not provide a good index for mortality in this river reach.

Comparison of signs of GBD between captive and migrant salmonids was not possible because salmonids were not targeted, and few were captured downstream from Ice Harbor Dam.

DISCUSSION

Mortality Rates of Captive Versus Sampled Fish

Mortality in resident fish populations cannot be properly evaluated through sampling because dead fish can rarely be recovered from the river. The 4-day holding tests in net-pens were considered a surrogate evaluation of mortality, but as previously mentioned, impacts from GBD were greater for captive fish than for free-swimming fish. However, we hoped that the combined data from multiple years of study would provide us with a reliable model relating GBD signs to mortality. Unfortunately, preliminary results using data from 1994 and 1995 have not been promising.

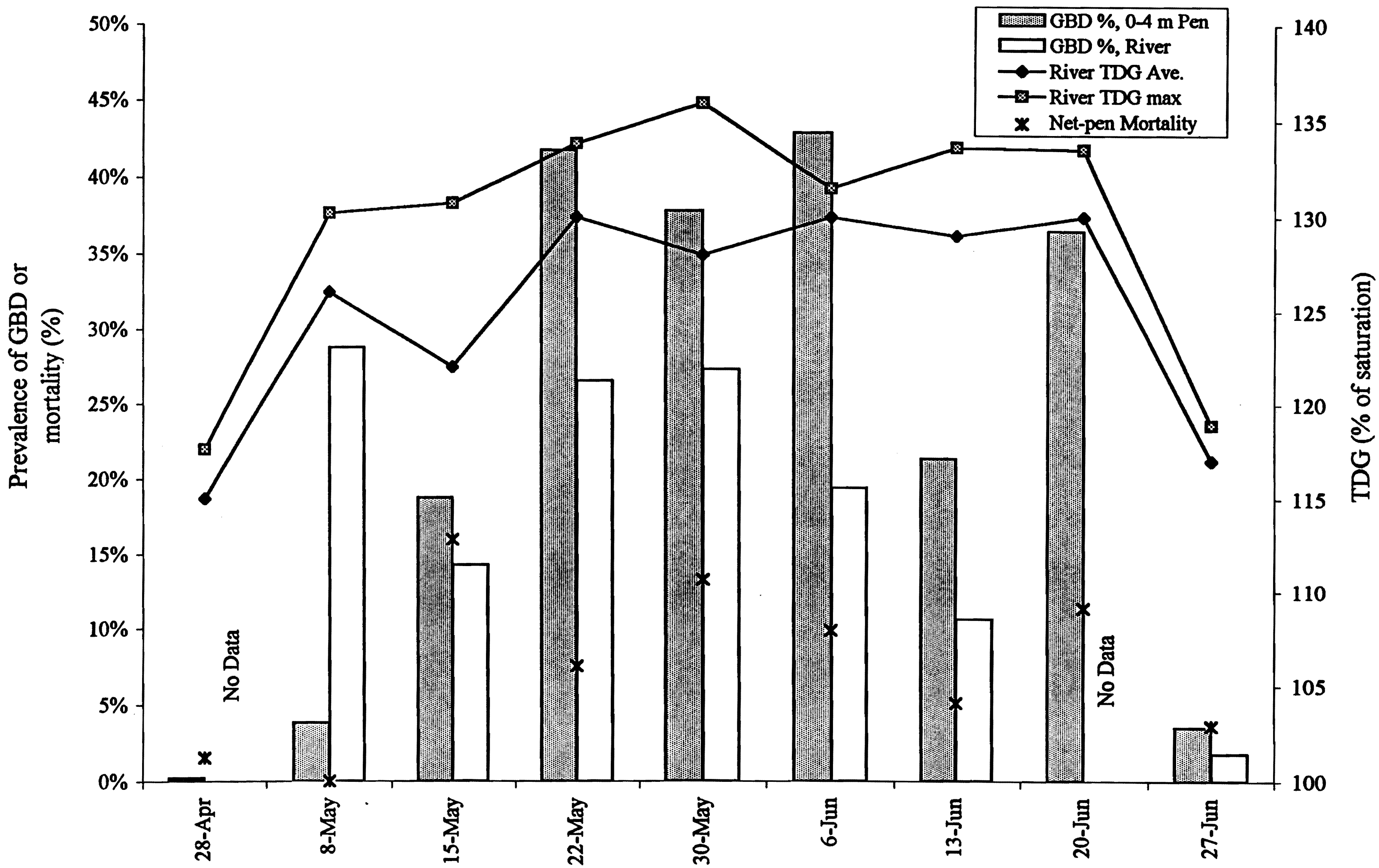

Figure 7. Signs of GBD in resident fish compared with signs of GBD and mortality of captive fish following 4-day holding tests related to average and maximum total dissolved gas (TDG) downstream from Ice Harbor Dam.

Table 14. Comparison of GBD prevalence between resident fish[a] (from sites within 7% of mean net-pen DGS) and resident fish from the net-pen after a 4-day holding period downstream from Ice Harbor Dam.

Date[b]	Fish from net-pen GBD (%)[c]	River samples the week following net-pen experiments. % GBD[d]	TDG in net pen during holding period Min[e]	Ave.[f]	Max[g]
April 24-28	0.0		110.2	115	117.6
	--	No Data	--	--	--
May 4-8	3.8		123.7	126	130.2
	--	28.8	--	--	--
May 11-15	18.8		115.6	122	130.7
	--	14.3	--	--	--
May 18-22	41.8		126.5	130	133.8
	--	26.6	--	--	--
May 26-30	37.9		115.9	128	135.9
	--	27.4	--	--	--
June 2-6	43.0		128.1	130	131.5
	--	19.5	--	--	--
June 9-13	21.4		117.3	129	133.6
	--	10.7	--	--	--
June 16-20	36.6		125.6	130	133.5
	--	No Data	--	--	--
June 23-27	3.5		115.7	117	118.9
	--	1.8	--	--	--

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 1).
[b] The date when fish were being held for net-pen experiments
[c] Percent of fish in net-pen with external signs of GBD at end of holding period.
[d] Percent of fish sampled from the river with external signs of GBD.
[e] Lowest dissolved gas measurement during 4-day holding period.
[f] Average dissolved gas measurement during 4-day holding period.
[g] Highest dissolved gas measurement during 4-day holding period.

Mortality rates of juvenile salmonids held in 0- to 4-m-deep net-pens also were not representative of river migrants because of water depth, exposure level, and duration. Based on average migration rates for run-of-the-river marked fish, chinook salmon migrating through the lower Snake River and McNary Reservoir spend about 12 hours in the river between Ice Harbor and McNary Dams (calculated from Berggren and Filardo 1993 or from PIT-tag data from 1995), where gas levels were highest and where our net-pen tests were conducted. Most sections of the migration corridor for which rates were calculated were in the slow-moving water of reservoirs, whereas the reach in question has a swift current. This consideration would have decreased the estimated time of passage through the reach.

Comparison to 1994 GBD study

In 1994 downstream from Bonneville Dam, we observed signs of GBD from 4 to 18 May (Toner et al. 1995). During this time, the highest DGS measured were 119% at a sampling site and 126.3% in the river channel. During the 1995 study, average gas levels in midriver were 116 to 117% of saturation. Signs of GBD were observed on two occasions at 8 and 29 June, when the highest DGS measured was 117.7% at the sampling site and 121.8% midriver.

Prevalence of GBD in resident fish collected downstream from Ice Harbor Dam was substantially higher in 1995 than in 1994. During the 1994 spill season, average DGS during peak spill ranged from 125% in early May to 118% of saturation in early June. In 1995, average levels of DGS during peak spill were near 128-130% from mid-May to mid-June. High prevalence of GBD was observed during this period, but relatively few instances of GBD were observed in the weeks after the daily average DGS had fallen to (and remained at) 118% of saturation or less.

A comparison between the 1994 and 1995 GBD prevalence in Priest Rapids Reservoir is difficult due to the relatively few samples taken in 1994.

Sampling

Many nonsalmonid fish, such as peamouth, bluegill, smallmouth bass, carp, sculpin, and yellow perch were collected in shallow areas, 1-m deep or less, with little current. These areas had cover for the fish, either in crevices of rip-rap or in aquatic vegetation. Largescale suckers were collected in nearshore areas at least 1.5-m in depth with swift current.

Shallow areas with little current usually had lower DGS than areas with swift current. Dell et al. (1974) also reported a difference of 6 to 8% of saturation between shallow and midriver areas in the mid-Columbia River. The lower DGS in backwater areas may be due to lack of exchange with higher DGS river water and greater gas dissipation from a larger surface-area to volume ratio. Differences in DGS between nearshore areas with swift current and shallow backwaters with little current were recorded on 2 June, when these areas had average DGS of 131.6 and 108.7%, respectively. Prevalence of GBD in resident fish collected from the near shore areas was 27.4% while prevalence from backwater areas was 3.1%.

Sampling was more successful when conducted just after sunrise. On occasion, collection was hampered because preferred collection sites had to be avoided due to the presence of fishermen.

We found no substantive GBD signs or GBD-related mortality among invertebrates even in environments where fish suffered severely. By contrast, in the laboratory experiments of Nebeker et al. (1976) and Brammer (1991), signs of GBD and GBD-related mortality in invertebrates occurred at the same dissolved gas levels which caused GBD signs and mortality in fish. These two different observations seem incongruous, but because of the consistency of our field data and similar negative data observed by Brammer (1991), we concluded that either invertebrates are less affected than fish or our sampling and holding techniques were biasing our results.

CONCLUSIONS AND RECOMMENDATIONS

Overall, we observed low prevalence of GBD signs in fish sampled during this study. However, because we did observe high prevalence of GBD signs in fish below Ice Harbor Dam when saturation levels exceeded 120%, we recommend GBD monitoring whenever DGS exceeds 120%.

The disparity between GBD signs in the river reach and the net-pen negated the use of mortality data from the net-pen as a direct index of mortality in the river, even in locations where DGS was highest. Therefore, we recommend that alternate locations for holding experiments be explored.

The long-term goal of this study is to develop a multiparameter model relating dissolved gas supersaturation levels (related to water flow and spill volumes) to signs of GBD and mortality in juvenile salmonids and other shallow-water organisms. Using regression analysis, we will compare duration and concentration of exposure to ambient dissolved gas levels with signs of GBD and mortality in organisms sampled from the river and held in net-pens at the three river sections.

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