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Evaluation of the effects of dissolved gas supersaturation on fish and invertebrates downstream from Bonneville, Ice Harbor, and Priest Rapids Dams, 1994

by
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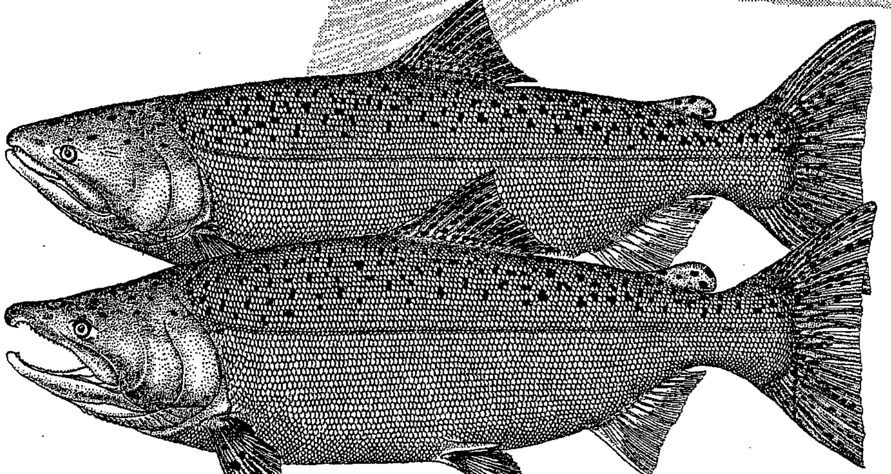

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EVALUATION OF THE EFFECTS OF DISSOLVED GAS SUPERSATURATION ON FISH AND INVERTEBRATES DOWNSTREAM FROM BONNEVILLE, ICE HARBOR, AND PRIEST RAPIDS DAMS, 1994

by

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INTRODUCTION

In 1991, Snake River sockeye salmon (*O. nerka*) were listed as endangered and in 1992, chinook salmon (*O. tshawytscha*) were listed as threatened under the Endangered Species Act. These listings have increased concern regarding passage survival at hydropower projects. Many studies have concluded that spill provides the safest passage route through dams on the Snake and Columbia Rivers and have prompted development of a spill regime to maximize survival of juvenile salmonid outmigrants.

Recent increases of spill at Columbia and Snake River dams have raised questions concerning the effects of increased levels of dissolved gas on aquatic biota. Supersaturation of dissolved atmospheric gases can cause gas bubble disease (GBD), which is potentially lethal to fish and invertebrates. Although spill-related high levels of dissolved gas supersaturation often occur in the Columbia and Snake River dams as a result of limited turbine capacity or energy demands, these recent attempts to increase passage survival of juvenile salmonids (*Oncorhynchus* spp.) by providing spill have caused increased dissolved gas levels over protracted river reaches and time periods.

During spring 1993 and spring 1994, dissolved gas levels in the Columbia and Snake Rivers often exceeded 110% of saturation, the maximum level established by the U.S. Environmental Protection Agency, Washington State Department of Ecology, Oregon State Department of Environmental Quality, and Idaho Department of Water Quality. Certain high levels of supersaturation were caused by high river flows for which there was no control. However, prior to and following the high river flows, supersaturation occurred as a result of spill for fish passage.

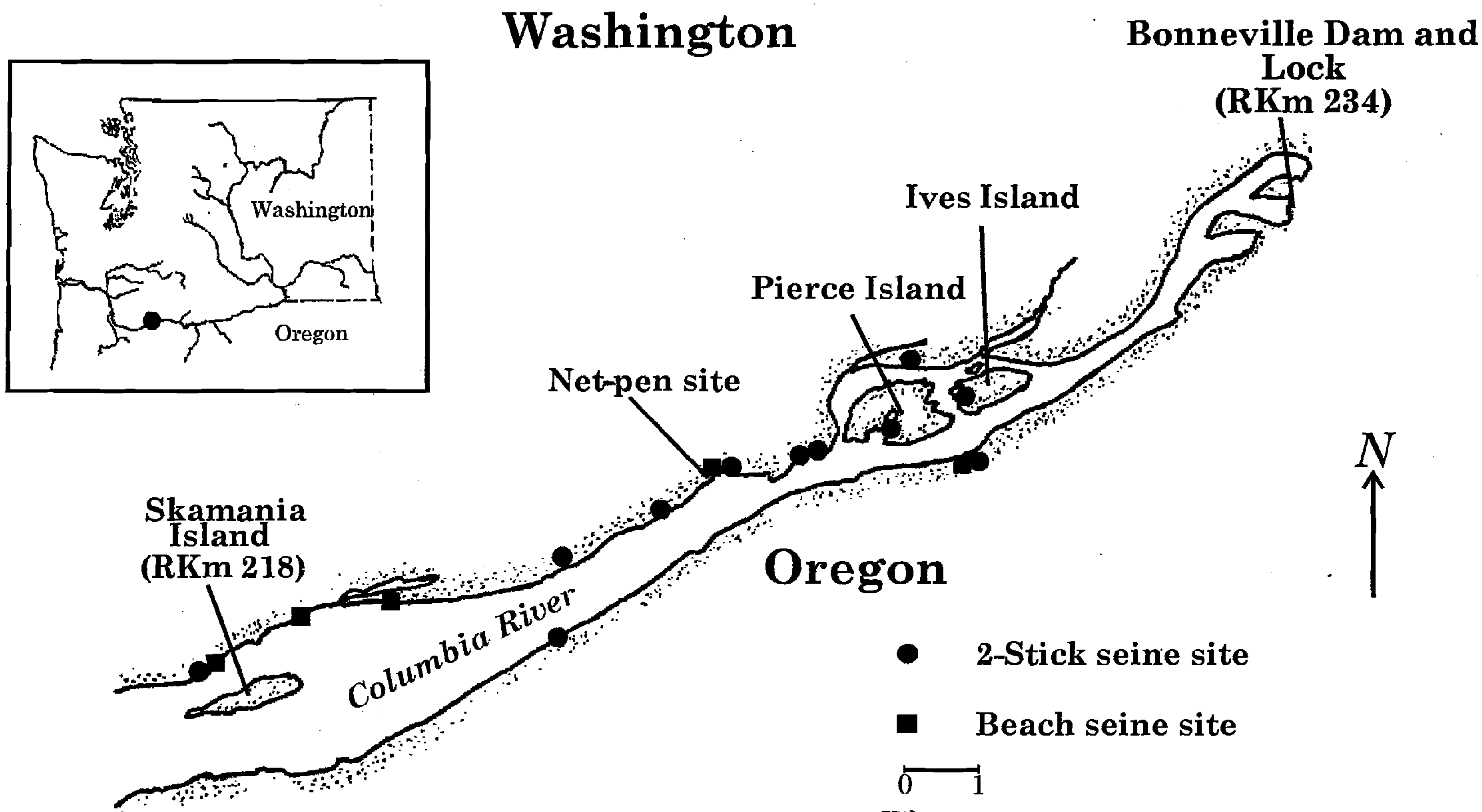

Figure 1.--Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in the Columbia River downstream from Bonneville Dam, 1994.

downstream from Ice Harbor Dam (RKm 13.7 to RKm 1.6) at least 2 times per week from 4 May to 1 July and from 25 July to 29 July 1994 (Fig. 2). In the mid-Columbia River, sampling was conducted downstream from Priest Rapids Dam in the Hanford Reach (RKm 600.2 to RKm 592.9) at least once each week from 10 May to 14 June (Fig. 3). Also in the mid-Columbia River, sampling was conducted occasionally in Priest Rapids Reservoir (RKm 650.5 to RKm 640.7) from 2 to 30 June (Fig. 4).

Sampling Methods

Up to 100 juvenile salmonids and 100 individuals each of other aquatic species were sampled weekly in each river reach. Downstream from Bonneville Dam, fish sampling was primarily conducted using a 7.5-m 2-stick seine with 12.7-mm webbing. Two people pulled the 2-stick seine upstream along the beach, collecting fish from no deeper than 1 m.

If there was sufficient depth in a sampling location, a 3.4-m-deep, 50-m variable-mesh beach seine was used for sampling. The beach seine consisted of four 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 on the beach and set the net in a wide arc with a 5-m outboard-powered boat, returning to the beach at an upstream point.

Electrofishing was the most effective means of collecting resident nonsalmonid fish species downstream from Ice Harbor Dam, downstream from Priest Rapids Dam, and in Priest Rapids Reservoir. Two electrofishing boats were used, and the bow platform of each boat was equipped with a pair of adjustable booms fitted with umbrella anode arrays. These arrays consisted of six stainless steel cables, which were lowered into the water when

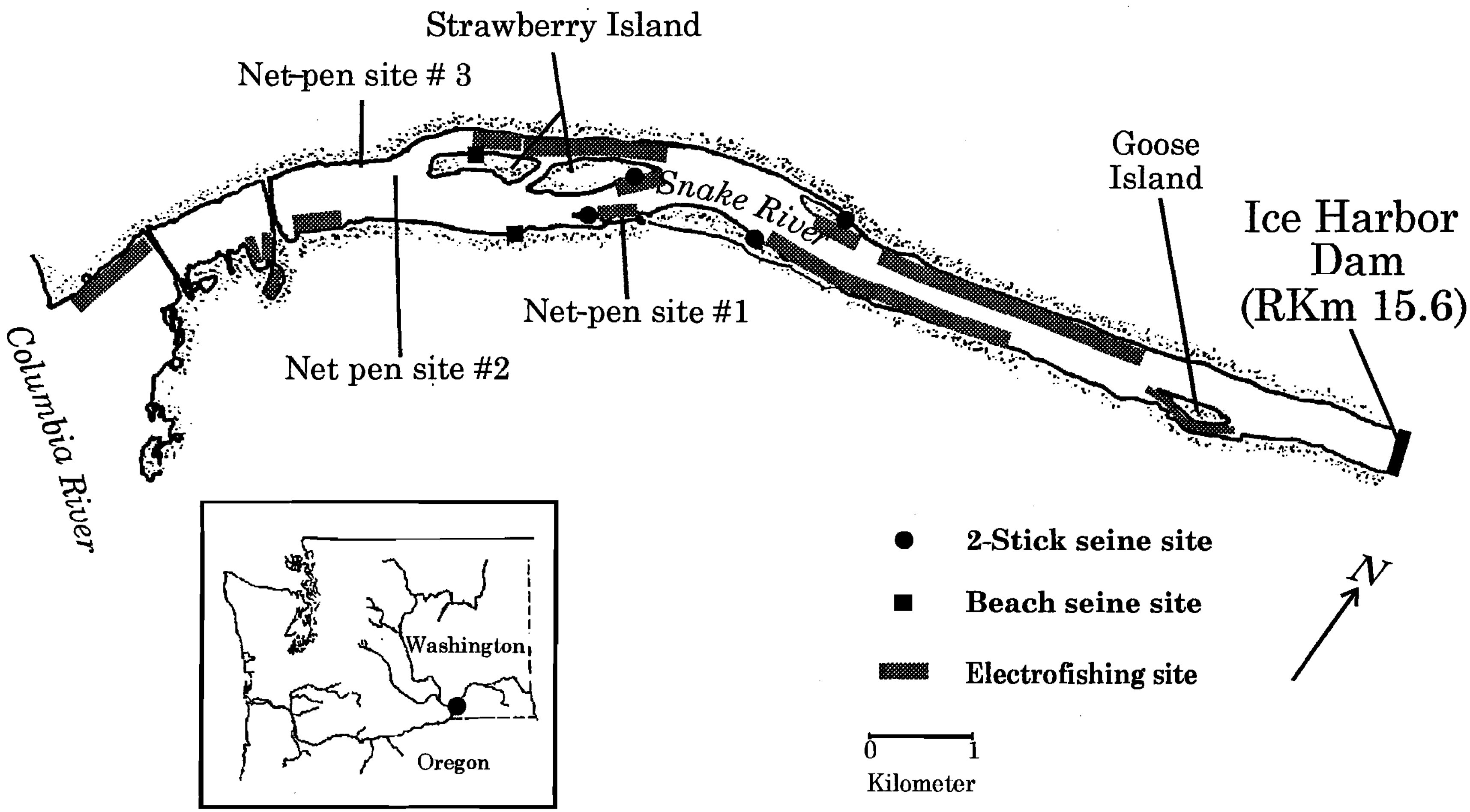

Figure 2.--Sampling sites for determining impacts of dissolved gas supersaturation on in the Snake River downstream from Ice Harbor Dam, 1994.

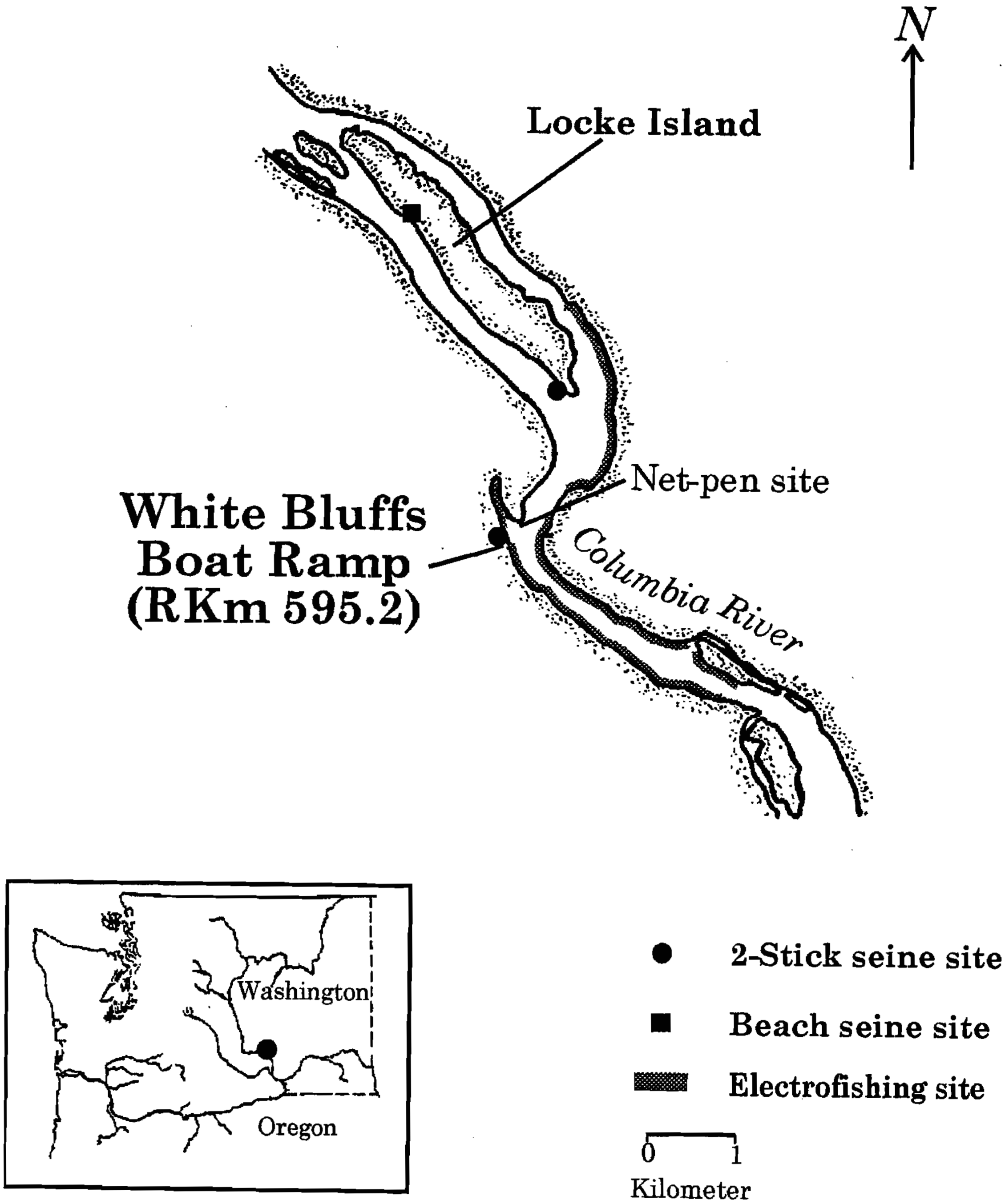

Figure 3. Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in the Hanford Reach of the Columbia River downstream from Priest Rapids Dam, 1994.

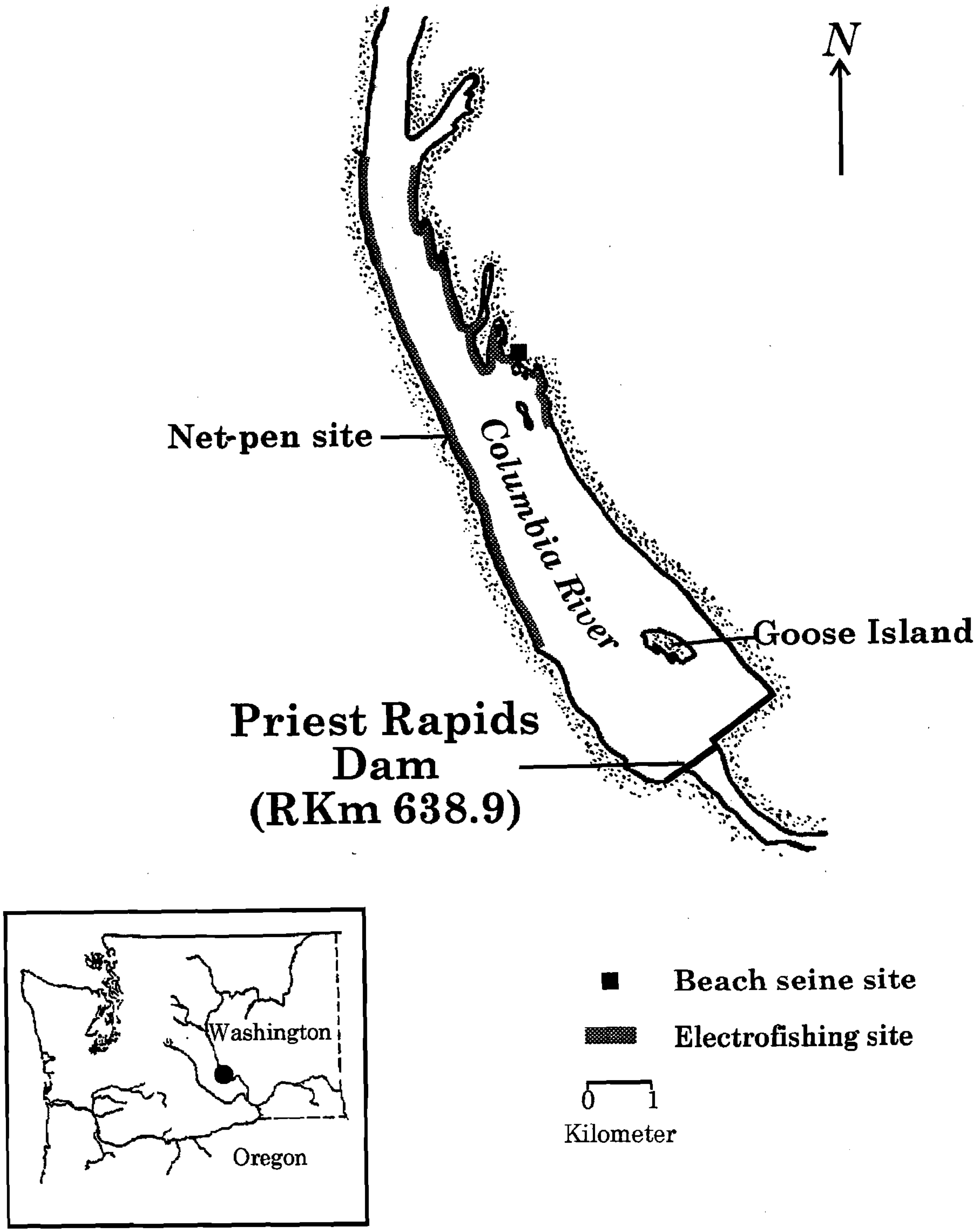

Figure 4. Sampling sites for determining impacts of dissolved gas supersaturation on aquatic biota in Priest Rapids Reservoir, Columbia River, 1994.

fishing. All electrofishing used pulsed direct current with 30 pulses/second, 400-500 volts, and 1-2 amperes.

All fish collected were anesthetized, identified, measured to the nearest mm and examined for external injuries. Up to 100 individuals of each species were examined with 2.5- to 5.0-power headband magnifying lenses. Samples were examined for external signs of GBD (subcutaneous emphysema on fins, head, eyes, and body surface). Internal examinations were not conducted.

Examinations were made immediately after sampling at the collection site. During the examination period, fish were held at ambient dissolved gas levels. All specimens were allowed to recover fully from the anesthetic prior to release.

Benthic and epibenthic macroinvertebrates were collected from depths of up to 0.6 m using a hydraulic epibenthic pump and Ponar bottom samplers. These samples were washed with water through a 0.5-mm screen, and all macroinvertebrates were retained. We examined organisms immediately after collection with a dissecting microscope using 10- to 40-power magnification.

Crayfish (*Pacifastacus leniusculus*) were examined for gas bubble emboli under the membrane between the carapace and abdominal segments using the method detailed by Nebeker et al. (1976). Other invertebrates were examined for gas bubble emboli in the body fluids, gut, and under the carapace by viewing through the body wall, as described by Nebeker et al. (1976).

A 0.6-m-diameter plankton net with 0.5-mm mesh was used to collect zooplankton samples near the water surface. We examined organisms immediately after collection with a dissecting microscope using 10- to 40-power magnification. Organisms were examined for gas bubble emboli as described above.

Nebeker et al. (1976) and White et al. (1991) documented the occurrence of both internal and external bubbles in aquatic macroinvertebrates. 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 rates and changes in prevalence of GBD were made for resident nonsalmonid species. Specimens were collected from each river reach, 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 and cages at two sites: downstream from Bonneville Dam and downstream from Ice Harbor Dam.

Three types of enclosures were used to hold fish: shallow perforated aluminum plate cages (0.6 x 0.6 x 1.0 m held at 0.5 m depth), deep submerged perforated aluminum plate cages (0.6 x 0.6 x 1.0 m held at 1.5 to 2.5 m depth), and large variable-depth net-pens (1.8 x 2.4 m). In the variable-depth net-pens, fish had access from the surface to a depth of 4 m. Up to 100 individuals of each species were held in these pens.

After 4 days, the fish from each of the three net-pen types were re-examined for external signs of GBD and other marks. A subsample of 10 hatchery chinook salmon were examined more carefully for gas bubbles in the lateral line using a microscope with 15-power magnification. All mortalities were examined for internal signs of GBD.

Dissolved Gas Measurements

Total dissolved gas and water temperature were measured at the time of sampling at each location and at the net-pens using tensionometers. We attempted to measure dissolved gas concentrations in 4-hour increments during net-pen holding experiments. Means and ranges of TDG during 4-day holding periods were determined from 4-hour data records and were sometimes different for salmonids and nonsalmonids because of differences in starting and ending times. However, these differences were less than 3% throughout the work period, and recalibration of tensionometers was not necessary. Evaluation of accuracy was based on comparisons with Weiss saturometers (Fickeisen et al. 1975).

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

RESULTS

GBD in Fish and Invertebrate Samples

Downstream from Bonneville Dam, 1,282 salmonids, 4,955 nonsalmonids, and 3,928 invertebrates were collected for a total of 23 taxa of invertebrates and 22 species of fish (Tables 1 and 2). Among all fish examined, only juvenile chinook salmon exhibited external signs of GBD: overall, 0.2% of these showed signs of GBD. Signs of GBD were seen only in early May when the highest TDG levels at sampling sites were measured (Table 3a-b).

Table 1. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Columbia River downstream from Bonneville Dam, 4 May - 25 August 1994.

Species	Scientific name	Sample (n)	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Peamouth	*Mylocheilus caurinus*	1,494	15-240	0	
Threespine stickleback	*Gasterosteus aculeatus*	1,479	18-65	0	
Chinook salmon	*O. tshawytscha*	1,227	35-173	3	0.2
Northern squawfish	*Ptychocheilus oregonensis*	1,025	21-239	0	
Largescale sucker	*Catostomus macrocheilus*	288	19-413	0	
Redside shiner	*Richardsonius balteatus*	276	22-136	0	
Smallmouth bass	*Micropterus dolomieui*	81	27-355	0	
Sculpin	*Cottus spp.*	70	18-156	0	
Coho salmon	*O. kisutch*	49	39-164	0	
American shad	*Alosa sapidissima*	40	35-130	0	
Yellow perch	*Perca flavescens*	16	90-135	0	
Carp	*Cyprinus carpio*	13	62-600	0	
Longnose dace	*Rhinichthys cataractae*	10	32-55	0	
Pumpkinseed	*Lepomis gibbosus*	10	86-155	0	
Bass	*Micropterus spp.*	9	16-23	0	
Steelhead	*O. mykiss*	6	120-222	0	
Brown bullhead	*Ictalurus nebulosus*	2	189-228	0	
Crappie	*Pomoxis spp.*	2	194-237	0	
Sandroller	*Percopsis transmontana*	2	61-66	0	
Largemouth bass	*Micropterus salmoides*	1	36	0	
White crappie	*Pomoxis annularis*	1	272	0	
White sturgeon	*Acipenser transmontanus*	1	550	0	
Unid. juveniles		135	12-78	0	
Total salmonids		1,282		3	0.2
Total non-salmonids		4,955		0	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 power headband magnifying lens.

Table 2. Numbers sampled and prevalence of gas bubble disease by species for invertebrates collected from the Snake and Columbia Rivers, 1994.

	Bonneville 4 May - 22 August			Ice Harbor 4 May - 28 July		
	Sample	GBD signs		Sample	GBD signs	
Taxa	(n)	(n)	(%)	(n)	(n)	(%)
Amphipoda	29	0		9	0	
Bryozoa	26	0		0	0	
Chironomidea	1,718	0		29	0	
Cladocera	1,167	0		79	3	4.0
Coleoptera	70	0		0	0	
Copepoda	229	0		9	0	
Corbicula	1	0		2	0	
Corophium	237	0		0	0	
Culicidae	0	0		4	0	
Diptera adult	19	0		1	0	
Diptera pupa	46	0		0	0	
Ephemeroptra	5	0		0	0	
Gastropoda	13	0		1	0	
Heleidae larva	1	0		0	0	
Hydracarina	71	0		21	0	
Hydrozoan	3	0		0	0	
Mysid	11	0		2	0	
Nematoda	20	0		3	0	
Nemertean	2	0		0	0	
Oligochaeta	216	0		24	0	
Ostracoda	1	0		0	0	
Pacifastacus	3	0		9	0	
Pelecypoda	5	0		0	0	
Trichoptera	2	0		0	0	
Turgellacia	1	0		0	0	
Unident. eggs	25	0		0	0	
Unident. Insecta	0	0		10	0	
Unident. pupa	6	0		0	0	
Unident. 3 tail nymph	1	0		0	0	—
Total invertebrates	3,928	0		203	4	1.5

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

Table 3a. Prevalence of signs of GBD in resident[a] fish and dissolved gas levels[b] for weekly sampling in the Columbia and Snake Rivers, 1994.

	Downstream from Bonneville Dam			Downstream from Ice Harbor Dam		
Dates	Sample (n)	GBD signs (n)	GBD signs (%)	Sample (n)	GBD signs (n)	GBD signs (%)
May 4-11		**TDG 113% (110-117%)**			**TDG 118% (107-132%)**	
	570	3	0.5	243	28	11.5
May 12-18		**TDG 114% (108-119%)**			**TDG 114% (107-120%)**	
	500	1	0.2	452	25	5.5
May 19-25		**TDG 117% (114-119%)**			**TDG 115% (108-125%)**	
	439	0	0.0	451	7	1.6
May 26-Jun 1		**TDG 110% (104-113%)**			**TDG 111% (107-115%)**	
	354	0	0.0	290	16	5.5
June 2-8		**TDG 111% (105-116%)**			**TDG 112% (106-119%)**	
	341	0	0.0	548	7	1.2
June 9-15		**TDG 109% (106-111%)**			**TDG 111% (97-126%)**	
	311	0	0.0	1,383	14	1.0
June 16-22		**TDG 111% (110-112%)**			**TDG 113% (110-115%)**	
	339	0	0.0	443	1	0.2
June 23-29		**TDG 111% (108-113%)**			**TDG 108% (103-114%)**	
	338	0	0.0	781	10	1.5
June 30-July 6		**TDG 109% (104-112%)**			**TDG 107% (106-109%)**	
	315	0	0.0	101	0	0.0
July 7-13		**TDG 110% (104-113%)**				
	485	0	0.0	0		
July 14-20		**TDG 112% (109-115%)**				
	632	0	0.0	0		
July 21-27		**TDG 109% (104-113%)**			**TDG 110% (99-116%)**	
	393	0	0.0	149	0	0.0
July 28-Aug 4		**TDG 110% (107-113%)**			**TDG 109% (93-114%)**	
	181	0	0.0	212	0	0.0
Aug 5-11		**TDG 111% (106-114%)**				
	340	0	0.0	0		
Aug 12-18		**TDG 113% (109-116%)**				
	314	0	0.0	0		
Aug 19-25		**TDG 111.5% (108-115%)**				
	385	0	0.0	0		

Table 3b. Prevalence of signs of GBD in resident[a] fish and dissolved gas levels[b] for weekly sampling in the mid-Columbia River, 1994.

Dates	Downstream from Priest Rapids Dam			Upstream from Priest Rapids Dam		
	Sample	GBD signs		Sample	GBD signs	
	(n)	(n)	(%)	(n)	(n)	(%)
May 4-11	**TDG 115% (114-115%)**					
	11	0	0.0	0		
May 12-18						
	0			0		
May 19-25	**TDG 112% (109-118%)**					
	401	0	0.0	0		
May 26-Jun 1	**TDG 111% (107-117%)**			**TDG 112% (106.6-117.4%)**		
	597	5	0.8	99	0	0.0
June 2-8	**TDG 106% (102-109%)**			**TDG 106% (105.5-106.2%)**		
	489	0	0.0	149	0	0.0
June 9-15	**TDG 102% (95-109%)**					
	432	0	0.0	0		
June 23-29				**TDG 107% (105.8-109.5%)**		
	0			378	0	0.0
June 30-July 6				**TDG 109% (107.5-109.7%)**		
	0			125	0	0.0

[a] Resident fish include all species of fish captured on the Columbia and Snake Rivers.
[b] Mean and range of total dissolved gas levels (% of saturation) measured at sampling sites at the time of sampling.

Signs of GBD were observed in 2% and 1%, of juvenile chinook salmon collected on 11 and 12 May, respectively. In midriver, TDG levels averaged 115.4 and 117.2% of saturation and peaked at 120.2% and 126.3%, respectively. At the times and sites of sampling, TDG measured 110.4% and 116.8%, respectively. Levels of TDG at the shallow-water sampling sites, where many fish and invertebrates reside, were most often less than midriver levels. The signs we observed were subcutaneous emphysema between rays of the caudal fins covering less than 10% of the fin surface.

Downstream from Ice Harbor Dam, 21 salmonids, 5,032 nonsalmonids, and 203 invertebrates were collected for a total of 12 taxa of invertebrates and 22 species of fish (Tables 2 and 4). Spill at Ice Harbor Dam caused high dissolved gas concentrations during May and early June: up to 136% of saturation in midriver and 132% at resident sampling sites (Table 3a). These gas levels produced the highest prevalence of GBD in any resident fish sampled at the three river reaches: prevalence of GBD signs reached a high of 11.5% of the weekly sample (Table 3a).

Throughout the study period, fish species displaying the highest prevalence of GBD were smallmouth bass (*Micropterus dolomieui*, 4.3%), yellow perch (*Perca flavescens*, 4.0%), largemouth bass (*Micropterus salmoides*, 3.3%), pumpkinseed (*Lepomis macrochirus*, 3.2%), and largescale suckers (*Catostomus macrocheilus*, 2.8%) (Table 4).

External signs of GBD varied among species, but the most prevalent were subcutaneous emphysema in the dorsal and/or caudal fins, with a majority of the fin surface often covered. Of the invertebrates sampled, only cladocera showed signs of GBD and only at a minimal prevalence (1.5%, Table 2).

Table 4. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Snake River downstream from Ice Harbor Dam, 4 May - 28 July 1994.

Species	Scientific name	Sample (n)	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Largescale sucker	*Catostomus macrocheilus*	1,244	20-615	35	2.8
Northern squawfish	*Ptychocheilus oregonensis*	847	9-468	7	0.8
Smallmouth bass	*Micropterus dolomieui*	828	41-467	36	4.3
Peamouth	*Mylocheilus caurinus*	749	61-260	1	0.1
Yellow perch	*Perca flavescens*	397	83-222	16	4.0
Sculpin	*Cottus spp.*	200	52-186	3	1.5
Bluegill	*Lepomis macrochirus*	151	40-202	2	1.3
Largemouth bass	*Micropterus salmoides*	122	36-425	4	3.3
Carp	*Cyprinus carpio*	95	277-730	1	1.1
Crappie	*Pomoxis spp.*	84	93-285	1	1.2
Brown bullhead	*Ictalurus nebulosus*	79	35-270	1	1.3
Redside shiner	*Richardsonius balteatus*	79	42-147	0	
Chiselmouth	*Acrocheilus alutaceus*	58	86-350	0	
Mountain whitefish	*Prosopium williamsonii*	52	45-224	0	
Pumpkinseed	*Lepomis gibbosus*	31	73-95	1	3.2
Steelhead	*O. mykiss*	11	63-277	0	
Chinook salmon	*O. tshawytscha*	7	60-95	0	
Sandroller	*Percopsis transmontana*	5	69-150	0	
Bridgelip sucker	*Catostomus columbianus*	4	111-475	0	
Coho salmon	*O. kisutch*	3	74-83	0	
American shad	*Alosa sapidissima*	2	410-412	0	
Channel catfish	*I. punctatus*	1	510	0	
Unidentified fry		11	24-32	0	
Total salmonids		21		0	0.0
Total non-salmonids		5,032		108	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 power headband magnifying lens.

Downstream from Priest Rapids Dam, 691 salmonids and 1,239 nonsalmonids were collected for a total of 18 individual species of fish (Table 5). Among fish examined, only largescale suckers showed signs of GBD (1% overall), with subcutaneous emphysema between fin rays of the dorsal, caudal, and ventral fins. These fish were collected on 26 and 31 May, when average TDG saturation measured 115.3 and 116.4% in midriver and 110.6 and 112.5% at sampling sites (Table 3b).

In Priest Rapids Reservoir, 1 salmonid, 750 nonsalmonids, and 2 invertebrates were collected for a total of 16 species of fish (Table 6) and one species of invertebrate. No signs of GBD were observed in any individuals, even though dissolved gas levels reached a high of 117.4% of saturation at one sampling site. Average TDG levels measured at sampling sites were 112% of saturation or less throughout the 26 May-6 July sampling period (Table 3b).

GBD in Captive Fish Groups

The results of net-pen holding experiments conducted downstream from Bonneville Dam with resident fish and hatchery chinook salmon are summarized in Table 7. Some signs of GBD were observed among captive fish in every 4-day holding period from 4 May through 10 June, when average TDG levels in the pens ranged from 114 to 117% 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 in the 0- to 4-m-deep net-pen.

Signs of GBD were primarily emboli in the lateral lines of hatchery salmon (up to 30%), but emboli were not seen consistently among test groups even when gas levels were similar. Subcutaneous emphysema between fin rays was observed less frequently (up to 20%), but prevelances were more consistent with TDG trends. The highest prevalence of

Table 5. Numbers sampled, size range, and prevalence of GBD by species for fish collected from the Columbia River downstream from Priest Rapids Dam, 10 May - 14 June 1994.

Species	Scientific name	Sample	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Chinook salmon	*O. tshawytscha*	674	40-95	0	
Largescale sucker	*Catostomus macrocheilus*	485	54-670	5	1.0
Peamouth	*Mylocheilus caurinus*	289	37-170	0	
Northern squawfish	*Ptychocheilus oregonensis*	188	39-510	0	
Redside shiner	*Richardsonius balteatus*	143	33-165	0	
Carp	*Cyprinus carpio*	81	330-710	0	
Mountain whitefish	*Prosopium williamsonii*	28	200-430	0	
Smallmouth bass	*Micropterus dolomieui*	16	124-539	0	
Coho salmon	*O. kisutch*	15	48-475	0	
Bridgelip sucker	*Catostomus columbianus*	3	454-514	0	
Threespine stickleback	*Gasterosteus aculeatus*	2	47-56	0	
Bluegill	*Lepomis macrochirus*	1	48	0	
Chiselmouth	*Acrocheilus alutaceus*	1	85	0	
Sculpin	*Cottus spp.*	1	81	0	
Sockeye salmon	*O. nerka*	1	120	0	
Steelhead	*O. mykiss*	1	180	0	
Walleye	*Stizostedion vitreum vitreum*	1	222	0	
Total salmonids		691		0	0
Total non-salmonids		1,239		5	0.4

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 power headband magnifying lens.

Table 6. Numbers sampled, size range, and GBD prevalence by species for fish collected from the Columbia River in Priest Rapids Reservoir, 1 - 30 June 1994.

Species	Scientific name	Sample	Length range[a] (mm)	Prevalence of GBD[b] (n)	Prevalence of GBD[b] (%)
Largescale sucker	*Catostomus macrocheilus*	196	130-588	0	
Northern squawfish	*Ptychocheilus oregonensis*	133	47-461	0	
Redside shiner	*Richardsonius balteatus*	87	46-130	0	
Peamouth	*Mylocheilus caurinus*	59	76-318	0	
Smallmouth bass	*Micropterus dolomieui*	59	65-483	0	
Sandroller	*Percopsis transmontana*	53	56-135	0	
Pumpkinseed	*Lepomis gibbosus*	47	53-154	0	
Sculpin	*Cottus spp.*	45	64-190	0	
Carp	*Cyprinus carpio*	28	218-721	0	
Bluegill	*Lepomis macrochirus*	24	68-156	0	
Chiselmouth	*Acrocheilus alutaceus*	8	71-213	0	
Threespine stickleback	*Gasterosteus aculeatus*	4	48-62	0	
Brown bullhead	*Ictalurus nebulosus*	3	139-176	0	
Yellow perch	*Perca flavescens*	3	157-165	0	
Chinook salmon	*O. tshawytscha*	1	71	0	
Largemouth bass	*Micropterus salmoides*	1	205	0	
Total salmonids		1		0	0
Total non-salmonids		750		0	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 power headband magnifying lens.

Table 7. Gas bubble disease in resident fish (non-salmonids) and hatchery reared subyearling fall chinook salmon held 4 days in river water downstream from Bonneville Dam, 1994.

	Resident fish[a]							Hatchery fall chinook salmon[b]						
	Intro. total[d]	GBD[e]	Samp.[f]	GBD signs external[g]		Mortalities[h]		Intro. total	Samp.	GBD signs external		LL[i]	Mortalities	
Date/ Conditions[c]	(n)	(%)	(n)	(n)	(%)	(n)	(%)	(n)	(n)	(n)	(%)	(%)	(n)	(%)
May 4-9			**TDG[j] 116% (111.1 - 121.1%)**											
Surface	35	0.0	36	3	8.3	0	0.0	0						
0-4 m	7	0.0	4	0	0	0	0.0	0						
Control	0							0						
May 9-13			**TDG 117% (113.5 - 126.3%)**						**TDG 117% (113.5 - 126.3%)**					
Surface	28	0.0	28	0	0	4	14.3	50[k]	55	11	20.0	10	0	0.0
0-4 m	120	0.0	94	0	0	3	3.2	50[k]	38	1	2.6	0	0	0.0
Control	24	0.0	24	0	0	0	0.0	20[k]	21	0	0.0	0	9	0.0
May 16-20			**TDG 115% (112.6 - 119.9%)**						**TDG 115% (112.6 - 119.9%)**					
Surface	58	0.0	55	1	1.8	5	9.1	50[k]	53	1	1.9	0	1	1.9
0-4 m	106	0.0	39	0	0	8	20.5	25[k]	30	0	0.0	0	0	0.0
Control	24	0.0	16	0	0	2	12.5	20[k]	20	0	0.0	0	0	0.0
May 23-27			**TDG 116% (107.3 - 121.3%)**						**TDG 116% (107.3 - 121.3%)**					
Surface	44	0.0	31	0	0	1	3.2	20	19	2	10.5	0	0	0.0
0-4 m	164	0.0	147	0	0	17	11.6	59	39	1	2.6	0	0	0.0
Control	15	0.0	14	0	0	1	7.1	20	18	0	0.0	10	0	0.
May 30- June 3			**TDG 114% (112.3 - 115.0%)**						**TDG 114% (112.3 - 116.6%)**					
Surface	18	0.0	7	1	14.3	0	0.0	25	25	1	4.0	0	0	0.0
0-4 m	46	0.0	46	0	0	4	8.7	51	48	0	0.0	10	0	0.0
Control	0							25	25	0	0.0	10	0	0.0
June 6-10			**TDG 114% (111.7 - 118.5%)**						**TDG 114% (111.7 - 118.3%)**					
Surface	65	0.0	64	1	1.6	6	9.4	25	24	1	4.2	30	0	0.0
0-4 m	158	0.0	150	0	0	0	0.0	57	47	0	0.0	20	0	0.0
Control	0	0.0						25	19	0	0.0	0	0	0.0
June 13-17			**TDG 112% (109.7 - 113.5%)**						**TDG 112% (109.7 - 113.5%)**					
Surface	29	0.0	27	0	0	6	22.2	27	23	0	0.0	0	3	13.0
0-4 m	223	0.0	222	0	0	0	0.0	55	55	0	0.0	0	8	14.5[l]
Control	0							25	23	0	0.0	10	0	0.0
June 20-24			**TDG 112% (108.8 - 115.4%)**						**TDG 115% (109.0 - 117.4%)**					
Surface	4	0.0	4	0	0	0	0.0	25	25	0	0.0	0	0	0.0
0-4 m	228	0.0	170	0	0	8	4.7	55	52	0	0.0	0	2	3.8[l]
Control	0							25	25	0	0.0	0	0	0.0
June 27- July 1			**TDG 111% (108.1 - 113.9%)**						**TDG 111% (108.1 - 113.9%)**					
Surface	3	0.0	3	0	0	0	0.0	25	26	0	0.0	0	0	0.0
0-4 m	155	0.0	141	0	0	4	2.8	52	49	0	0.0	0	10	20.4[l]
Control	0							25	25	0	0.0	0	0	0.0
July 5-9			**TDG 112% (108.3 - 115.8%)**						**TDG 112% (108.3 - 115.8)**					
Surface	0							25	25	1	4.0	10	0	0.0
0-4 m	102	0.0	41	0	0	10	24.4	46	38	0	0.0	0	18	47.4[l]
Control	0							25	25	0	0.0	0	0	0.0

Table 7. Continued.

Date/ Conditions[c]	Resident fish[a] Intro. total[d] (n)	GBD[e] (%)	Samp.[f] (n)	GBD signs external[g] (n)	(%)	Mortalities[h] (n)	(%)	Hatchery fall chinook salmon[b] Intro. Total (n)	Samp. (n)	GBD signs external (n)	(%)	LL[i] (%)	Mortalities (n)	(%)
July 11-15			**TDG 111% (108.7 - 114.2%)**							**TDG 111% (108.7 - 114.2%)**				
Surface	0							25	25	1	4.0	0	0	0.0
0-4 m	245	0.0	175	0	0	29	16.6	53	48	0	0.0	0	17	35.4[l]
Control	0							25	18	0	0.0	0	0	0.0
July 18-22			**TDG 112% (109.9 - 116.2%)**							**TDG 112% (109.9 - 116.2%)**				
Surface	0							25	25	0	0.0	0	0	0.0
0-4 m	83	0.0	48	0	0	36	75.0	53	47	0	0.0	0	0	0.0
Control	0							25	25	0	0.0	0	0	0.0
July 25-29			**TDG 112% (109.7 - 114.7%)**							**TDG 112% (109.7 - 114.7%)**				
Surface	2	0.0	0	0	0	2	100.0	25	25	1	4.0	0	0	0.0
0-4 m	252	0.0	211	0	0	29	13.7	52	52	0	0.0	0	12	23.1[l]
Control	0							25	25	0	0.0	0	0	0.0
August 1-5			**TDG 114% (110.7 - 113.7%)**							**TDG 114% (110.7 - 116.0%)**				
Surface	0							25	25	1	4.0	0	0	0.0
0-4 m	181	0.0	78	0	0	73	93.6	44	46	0	0.0	0	4	8.7[l]
Control	0							25	25	0	0.0	0	4	16.0
August 8-12			**TDG 113% (107.8 - 117.0%)**							**TDG 113% (107.8 - 117.0)**				
Surface	2	0.0	2	0	0	2	100.0	25	25	1	4.0	0	1	4.0
0-4 m	120	0.0	105	0	0	33	31.4	64	57	0	0.0	0	6	10.5[l]
Control	0							25	25	0	0.0	0	1	4.0
August 15-19			**TDG 115% (111.2 - 116.5%)**							**TDG 115% (111.2 - 116.5%)**				
Surface	0							25	25	2	8.0	0	1	4.0
0-4 m	124	0.0	90	0	0	74	82.2	53	51	0	0.0	0	5	9.8[l]
Control	0							25	25	0	0.0	0	0	0.0

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 1).
[b] Fork length range; 50 to 94 mm in May increasing to 78 to 119 mm in August.
[c] Conditions of holding: Surface -- in a cage 0.6-m x 0.6-m x 1-m tall located at surface to 1-m depth; 0-4 m -- in a net-pen 1-m x 2.6-m x 4-m deep; Control -- in a cage 0.6-m x 0.6-m x 1-m tall located at 2 to 3 m depth.
[d] Number of individuals introduced into the holding container.
[e] Percentage of individuals displaying external signs of GBD at introduction.
[f] Number of individuals observed for signs of gas bubble disease at test termination. Differences between numbers introduced and sampled reflect loss due to predation, breaches in the pens.
[g] External signs only, including subcutaneous emphysema on fins, head, mouth, eyes, and body surface.
[h] Throughout the evaluation period, no external or internal signs were observed on or in mortalities.
[i] The percentage of ten salmon from each holding pen displaying emboli in the lateral line.
[j] Mean and (range) of dissolved gas levels; percent of saturation.
[k] Estimated at introduction.
[l] Mortalities likely associated with net entanglement on the river bottom.

subcutaneous emphysema was observed in the test conducted from 9 through 13 May, when gas levels peaked at 126.3% of saturation.

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

Results of net-pen holding experiments with resident fish and hatchery chinook salmon conducted downstream from Ice Harbor Dam are summarized in Table 8. The highest prevalence of signs of GBD were observed during holding experiments conducted from 9 May to 13 May and 23 May through 17 June.

Prevalence of subcutaneous emphysema between fin rays ranged from 12 to 50% for salmon held in the surface cages and from 0 to 37.5% for salmon held in the 0- to 4-m net-pen. Salmon held in the control cages at 1.5- to 2.5-m depths displayed these signs only during the 9-13 May test at 10% prevalence; on those days, TDG levels averaged 125% but reached a high of 135.1% of saturation.

Gas emboli in lateral lines were observed on 80% of the salmon from surface cages in two tests, but as in tests downstream from Bonneville Dam, these signs were not closely related to TDG levels. Prevelances of GBD signs among captive resident fish ranged from 0 to 40%. Even though these resident fish had been previously exposed to supersaturated

Table 8. Gas bubble disease in resident fish (non-salmonids) and hatchery reared subyearling fall chinook salmon held 4 days in river water downstream from Ice Harbor Dam, 1994.

Date/ Conditions[c]	Resident fish[a] Intro. total[d] (n)	GBD[e] (%)	Samp.[f] (n)	GBD signs external[g] (n)	GBD signs external[g] (%)	Mortalities[h] (n)	Mortalities[h] (%)	Hatchery fall chinook salmon[b] Intro. total (n)	Samp. (n)	GBD signs external (n)	GBD signs external (%)	LL[i] (%)	Mortalities (n)	Mortalities (%)
May 4-9			**TDG[j] 115% (111.1 - 119.3%)**											
Surface	0							0						
0-4 m	3	0.0	3	0	0	0	0.0	0						
Control	0							0						
May 9-13			**TDG 125% (119.7 - 135.1%)[k]**						**TDG 125% (119.7 - 135.1%)[k]**					
Surface	12	0.0	2	0	0	0	0.0	20	16	2	12.5	--	14	87.5
0-4 m	38	14.3	10	4	40	0	0.0	62	55	16	29.0	--	2	3.6
Control	4	0.0	4	0	0	0	0.0	10	10	1	10.0	--	2	20.0
May 16-20			**TDG 121% (118.9 - 121.8%)[k]**						**TDG 121% (118.9 - 121.8%)[k]**					
Surface	0							20	20	0	0.0	--	0	0.0
0-4 m	132	5.4	113	1	0.9	12	10.6	67	28	1	3.6	--	2	7.1[l]
Control	0							12	12	0	0.0	--	0	0.0
May 23-27			**TDG 121% (120.1 - 122.2%)[k]**						**TDG 121% (120.1 - 122.2%)[k]**					
Surface	10	0.0	10	3	30	0	0.0	20	18	9	50.0	40	2	11.1
0-4 m	75	0.0	74	3	4.1	2	2.7	64	8	3	37.5	0	1	12.5
Control	20	0.0	19	0	0	0	0.0	15	15	0	0.0	0	0	0.0
May 30- June 3			**TDG 121% (119.5 - 122.6%)[k]**						**TDG 121% (119.5 - 122.6%)[k]**					
Surface	0		4	0	0	0	0.0	20	20	2	10.0	80	0	0.0
0-4 m	142	3.4	98	2	2.0	2	2.0	57	‘54	3	5.6	0	0	0.0
Control	0		5	1	20	0	0.0	20	20	0	0.0	0	0	0.0
June 6-10			**TDG 120% (118.8 - 121.7%)[k]**						**TDG 120% (118.8 - 121.7%)[k]**					
Surface	0							25	24	8	33.3	80	1	4.2
0-4 m	117	0.7	90	1	1.1	14	15.6	48	47	0	0.0	10	0	0.0
Control	0							25	25	0	0.0	0	0	0.0
June 13-17			**TDG 118% (116.8 - 118.8%)[j]**						**TDG 118% (116.8 - 118.8%)[j]**					
Surface	11	0.0	8	0	0	0	0	25	18	8	44.4	20	4	22.2
0-4 m	244	2.4	200	0	0	6	3.0	51	49	1	2.0	0	0	0.0
Control	10		Pen lost					25	Pen lost					
June 20-24			**TDG 113% (104.6 - 119.6%)[j]**						**TDG 115% (104.6 - 116.0%)[j]**					
Surface	10	0.0	7	0	0	3	42.9	25	25	1	4.0	0	0	0.0
0-4 m	195	0.0	186	0	0	0	0.0	55	48	0	0.0	0	0	0.0
Control	10	0.0	5	0	0	1	20.0	25	24	0	0.0	0	0	0.0

Table 8. Continued.

	Resident fish[a]							Hatchery fall chinook salmon[b]						
	Intro.			GBD signs				Intro.		GBD signs				
Date/	total[d]	GBD[e]	Samp.[f]	external[g]		Mortalities[h]		total	Samp.	external		LL[i]	Mortalities	
Conditions[c]	(n)	(%)	(n)	(n)	(%)	(n)	(%)	(n)	(n)	(n)	(%)	(%)	(n)	(%)
June 27- July 1:			**TDG 108% (98.3 - 112.6%)[k]**							**TDG 108% (98.3 - 112.6%)[k]**				
Surface	10	1.4	10	0	0	0	0.0	25	24	0	0.0	0	1	4.2
0-4 m	220	0.0	217	0	0	22	10.1	51	51	0	0.0	0	0	0.0
Control	10	0.0	0	0	0	0	0.0	25	25	0	0.0	0	4	16.0
July 5-9, July 11-15, and July 18-22				**No Experiments**										
July 25-29										**TDG 112% (110.9-114.9%)[j]**				
Surface	0							25	25	0	0.0	0.0	0	0.0
0-4 m	0							53	52	0	0.0	0.0	1	1.9
Control	0							25	25	0	0.0	0.0	0	0.0

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 4).
[b] Fork length range; 50 to 94 mm in May increasing to 78 to 119 mm in August.
[c] Conditions of holding: Surface --in a cage 0.6-m x 0.6-m x 1-m tall located at surface to 1-m depth; 0-4 m -- in a net pen 1-m x 2.6-m x 4-m deep; Control -- in a cage 0.6-m x 0.6-m x 1-m tall located at 2 to 3 m depth.
[d] Number of individuals introduced into the holding container.
[e] Percentage of individuals displaying external signs of GBD at introduction.
[f] Number of individuals observed for signs of gas bubble disease at test termination. Differences between numbers introduced and sampled reflect loss due to predation and breaches in the net-pens or cages.
[g] External signs only, including subcutaneous emphysema on fins, head, mouth, eyes, and body surface.
[h] Throughout the evaluation period, no external or internal signs of GBD were observed on or in mortalities.
[i] The percentage of fish in a sample of 10 salmon from each holding pen displaying emboli in the lateral line.
[j] Mean and (range) of TDG in percent of saturation at the net-pen.
[k] TDG data from the COE 6 RKm station because of pen monitoring failure in the net-pen.
[l] Mortalities likely associated with heavy current.

conditions in the river, they generally displayed lower prevalence of GBD than salmon held 4 days.

Holding tests using resident species were conducted downstream from Priest Rapids Dam only during 31 May-17 June, and no signs of GBD were observed in any of these groups (Table 9). Dissolved gas levels averaged from 110 to 114% and reached a maximum of 116.4%.

DISCUSSION

Comparison to 1993 GBD Study

In the 1993 study downstream from Bonneville Dam, we observed signs of GBD in juvenile salmonids and in nonsalmonid fish from 19 May through 9 June (Toner and Dawley 1995). During that time, the highest TDG level measured at a sampling site was 122% at Rooster Rock, Oregon (RKm 209). In 1994, at sampling sites 10 to 20 km upstream (RKm 219-229), the maximum TDG measured was 119%. In both 1993 and 1994, we observed low overall prevalence of GBD in juvenile chinook salmon: 0.1% in 1993 and 0.2% in 1994. However, in 1993 we also observed GBD in 3% of juvenile coho salmon and 2% of juvenile steelhead, as well as in 3 species of nonsalmonid fish: 0.6% of prickly sculpin, 0.4% of peamouth, and 0.2% of threespine stickleback. Other river reaches were not evaluated in 1993.

Comparison to GBD at Dams

In 1994, prevalence of external signs of GBD in juvenile salmonids seined from the river or held in net-pens downstream from Bonneville Dam was similar to that observed in salmonids collected by the Smolt Monitoring Program (SMP) at Bonneville Dam (Columbia

Table 9. Gas bubble disease in resident fish (non-salmonids) held 4 days in river water downstream from Priest Rapids Dam, 1994.

Date/ Conditions[b]	Resident fish[a] Introduction total[c] (n)	GBD[d] (%)	Sample[e] (n)	GBD signs external[f] (n)	(%)	Mortalities[g] (n)	(%)
May 31 June 4		**TDG[h] 114% (112.5 - 116.4%)**					
Surface	0						
0-4 m	152	0	107	0	0	44	41.1[i]
Control	0						
June 7-12		**TDG 110% (109.8 - 110.6%)**					
Surface	52	0	4[j]	0	0	1	25.0[j]
0-4 m	65	0	43	0	0	5	11.6[i]
Control	0						
June 13-17		**TDG 110% (109.8 - 111.6%)**					
Surface	14	0	8	0	0	0	0
0-4 m	196	0	195	0	0	0	0
Control	8	0	8	0	0	0	0

[a] Resident fish sampled from the river reach, size range from juvenile to adults (Table 5).
[b] Conditions of holding: Surface --in a cage 0.6 m x 0.6 m x 1 m tall located at surface to 1 m depth; 0-4 m -- in a net pen 1 m x 2.6 m x 4 m deep; Control -- in a cage 0.6 m x 0.6 m x 1 m tall located at 2 to 3 m depth.
[c] Number of individuals introduced into the holding container.
[d] Percentage of individuals displaying external signs of GBD at introduction.
[e] Number of individuals observed for signs of gas bubble disease at test termination. Differences between numbers introduced and sampled reflect loss due to predation and breaches in the pens or cages.
[f] External signs only, including subcutaneous emphysema on fins, head, mouth, eyes, and body surface.
[g] Throughout the evaluation period, no external or internal signs of GBD were observed on or in mortalities.
[h] Mean and (range) of dissolved gas levels; percent of saturation.
[i] Mortalities likely associated with heavy current.
[j] Loss and mortality associated with breach in pen.

Basin Fish and Wildlife Authority 1994). From 11 to 12 May, signs of GBD were observed in 1 to 2% of seined juvenile chinook salmon, whereas no signs were observed at Bonneville Dam.

In holding experiments ending 13 and 27 May, 2.6% of hatchery chinook salmon held in 0- to 4-m net-pens exhibited GBD signs. Although the SMP at Bonneville Dam observed no signs of GBD in juvenile chinook salmon, they did observe GBD signs in 0.9 to 5.6% of steelhead (*O. mykiss*) from 13 May through 28 May.

Prevalence of external signs of GBD in juvenile salmonids sampled downstream from Ice Harbor Dam was dissimilar to those observed in salmonids collected by the Smolt Monitoring Program (SMP) at Lower Monumental and McNary Dams (there was no sampling at Ice Harbor Dam). Although we observed no signs of GBD in the few juvenile salmonids (11 hatchery steelhead, 7 chinook and 2 coho salmon) collected near Ice Harbor Dam during 9 weeks of sampling, the SMP at Lower Monumental Dam observed GBD signs in 0.1 to 1.1% of chinook salmon from 14 through 16 May, and in 0.2 to 1.2% of steelhead from 15 through 23 May. At McNary Dam the SMP observed GBD signs in 1.0% of chinook salmon on 21 May and in 1.1 to 16.7% of steelhead from 27 May through 3 June.

The results of net-pen holding for juvenile salmon downstream from Ice Harbor Dam suggested a greater impact from TDG than SMP samples at the dams. During the four holding experiments from 9 May through 3 June, subcutaneous emphysema occurred in 3.6 to 37.5% of the salmon held in the 0- to 4-m-deep net-pen. The Ice Harbor Dam tailrace had substantially higher TDG than upstream and downstream stretches of the river. Therefore, effects observed in net-pen-held fish can only be compared with fish residing in that river reach for an extended period. It is probable that migrating juvenile salmon migrated through the 10 miles downstream from the dam in only a few hours and therefore were exposed to less TDG than those captive in the net-pen. Also, captive individuals suffer behavior changes related to confinement, flow conditions, and fish interaction which affect their swimming activity, feeding ability, and vertical distribution.

GBD in the Hanford Reach

The Hanford Reach is a fall chinook salmon rearing area. This reach was not extensively sampled in 1993, when TDG levels downstream from Priest Rapids Dam reached 130% of saturation. However, in early June 1993, the Columbia River Inter-Tribal Fish Commission (CRITFC) tagged juvenile salmon in this area and reported no signs of GBD (Jeff Fryer, CRITFC, Portland OR, Pers. commun., July 1993).

During our sampling in 1994, the highest TDG measured in this reach was 118.3%, a reading taken on 24 May at our net-pen site. At Hanford Reach sampling sites, TDG ranged from 110.0 to 112.5%, and we observed no signs of GBD in resident salmonids. However, at that time, CROHMS TDG levels measured downstream from Priest Rapids Dam were unreliable because of a meter malfunction. Based upon TDG levels in the forebay and spill flow percentages, we estimate that levels downstream may have peaked at upwards of 125% of saturation.

Comparison to 1974 GBD Study

We sampled in Priest Rapids Reservoir because of its high TDG levels and because the results of an extensive dissolved gas study conducted in 1974 were available for comparison (Dell et al. 1974). We attempted to sample the same areas as Dell et al., using similar gear. However, sedimentation and plant and algae growth precluded the use of previously sampled beach seine sites.

We observed no signs of GBD in fish collected in Priest Rapids Reservoir, while Dell et al. (1974) reported that 10.6% of the 29,273 fish examined showed signs of GBD. Dell et al. reported an even higher prevalence of GBD signs in spawning suckers in shallow water in May and June. The TDG levels in 1974 were above 120% of saturation from 22 May through 2 August, and were above 125% from 12 June through 4 July. In 1994, lower TDG levels and the shorter duration of high TDG corresponded with the lower prevalence of GBD signs.

Sampling Problems

We were unable to sample prior to the spill season because we had not yet received an Endangered Species Act sampling permit. This was a disadvantage for us downstream from Ice Harbor Dam, in the Hanford Reach, and in Priest Rapids Reservoir because we had no previous sampling experience in these locations. It took several weeks of sampling to locate areas suitable for collecting fish.

Many nonsalmonid fish, such as peamouth, bluegill, smallmouth bass, carp, sculpin, and yellow perch were collected in shallow areas, 1 m or less in depth, 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 near-shore areas at least 1.5-m deep with swift current.

Shallow areas with little current usually had lower TDG levels than the areas with swift current. Dell et al. (1974) also reported a difference of 6 to 8% of saturation between shallow and midriver areas and in the mid-Columbia River. The lower TDG levels in backwater areas may be due to lack of exchange with the higher TDG river water and greater gas dissipation from a larger surface-area-to-volume ratio.

Sampling was more successful when conducted at least 1 hour before sunrise. On occasion, collection was hampered because preferred collection sites had to be avoided due to the presence of fishermen.

During June, lower water levels dewatered some of our established collection areas, forcing fish to move out of the rocks or vegetation that provided cover. This was particularly noticeable in the inlet on the southeast shore of Strawberry Island at Snake River RKm 7.3.

Net-Pen Study Problems

Downstream from Ice Harbor Dam, our initial site for the net-pen had sufficient depth and moderate current, and appeared to have TDG levels that were close to those measured in midriver. However, once spill was initiated on 11 April, the saturation measurements showed insufficient mixing of midriver water with that of the side channel. This was especially evident on 28 April, when the TDG measured at the north shore (1.7 km upstream from the net-pen site), where the main river flow is concentrated, was 120.6% of saturation, while the TDG measured at the net-pen one-half hour later was 113.2%.

There were also large quantities of brown filamentous algae which became entangled on the netting of the net-pen and blocked water flow within 45 minutes of deploying the net. The second site where we anchored the net-pen (Fig. 2) (for the three holding experiments conducted from 9 through 27 May) had sufficient depth and dissolved gas saturation, but the current was too strong despite the installation of flow deflector panels.

During peak spill times, the bow of the net-pen "nose-dived" in the water, allowing fish to escape. The third net-pen site, which was selected for the net-pen holding experiment starting 30 May (Fig. 2), had sufficient depth, TDG levels representing the spill side of the river, and moderate current.

Originally, we proposed daily examinations of all organisms held in the net-pens for signs of GBD and for mortality. However, we stopped daily exams because of the stress imposed on test fish during retrieval. Therefore, organisms were examined initially and at the conclusion of the 4-day holding period. The disadvantage of examining fish only at the conclusion of the tests was that mortalities were often dead for too long to determine whether fish had died as a result of GBD. This was especially true when the water temperature reached 18°C and higher.

Another problem with the 0- to 4-m-deep net-pen located downstream from Ice Harbor Dam was that it did not have a partition, so that hatchery chinook salmon were held in the same pen with resident nonsalmonid fish. We selected nonsalmonid fish that were less than 140-mm total length to avoid predation. However, even with this precaution, smallmouth bass apparently preyed on the hatchery chinook salmon, since reduced numbers of hatchery chinook salmon were recovered at the conclusion of the early experiments (Table 8). Following these experiments, a partition was added to the net-pen so that hatchery chinook salmon were separated from other fish. In the subsequent experiments, losses were significantly reduced.

In the 0- to 4-m net-pen anchored downstream from Bonneville Dam, a high mortality rate for hatchery chinook salmon was observed between 27 June and 29 July. Dropping river levels had caused this net-pen to become entangled with a mooring anchor line, and the problem was not seen until the net-pen was removed. Also, the water level had dropped sufficiently so that the support poles for the 4-m-depth corners of the net-pen were within 0.6 m of the bottom, and the bottom of the net may have become fouled on debris at the river bottom. There were no apparent mortalities for fish held in the surface or control net-pens.

CONCLUSIONS AND RECOMMENDATIONS

Overall, we observed low prevalence of GBD signs in fish under sampling conditions during this study. However, because we did observe high prevalence of GBD signs in fish when saturation levels exceeded 125% below Ice Harbor Dam, we recommend that monitoring of TDG should be coordinated with sampling to monitor GBD when high TDG levels occur.

We did not observe signs of GBD in the few salmonids collected downstream from Ice Harbor Dam. However, based on the high prevalence of GBD signs observed in hatchery chinook salmon held in net-pens when the average TDG levels exceeded 115% saturation, we recommend smolt monitoring at Ice Harbor Dam when TDG exceeds 115%.

In 1993 and 1994, no signs of GBD were observed in naturally rearing fall chinook salmon in the river reach near Locke Island. We believe that TDG was sufficiently dissipated in the 40 km of free-flowing river downstream from Priest Rapids Dam to provide relatively safe gas levels for resident fishes. Resident fish sampling and net-pen holding any closer to the dam can not easily be conducted. Thus, future GBD assessments in this reach will be moved to Priest Rapids Reservoir.

A 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 or held in net-pens at the three river reaches.

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