Evaluation of the effects of dissolved gas supersaturation on fish and invertebrates downstream from Bonneville Dam, 1993

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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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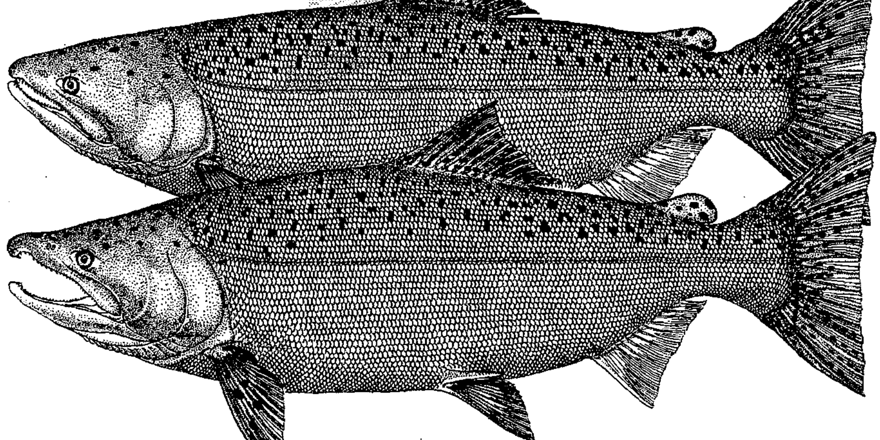
March 1995



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CONTENTS

ABSTRACT 1

INTRODUCTION 2

METHODS 4

Sampling 4

Live-Cage Study 9

RESULTS 10

DISCUSSION 26

CONCLUSIONS 32

REFERENCES 33

APPENDIX 35

ABSTRACT

During the period of high spring flow in the Columbia River in 1993, the occurrence of gas bubble disease (GBD) in migrating juvenile salmonids and other aquatic biota residing in the Columbia River downstream from Bonneville Dam was monitored. Fishes and invertebrates were collected with a 50-meter beach seine, a 7.5-meter seine and a Ponar bottom sampler at 18 locations from Columbia River Kilometer (RKm) 228 to 62. Dissolved gas saturation values at the U.S. Army Corps of Engineers' Warrendale, Oregon monitoring station (RKm 226) reached 128% on 4 days, with daily mean values above 120% on 9 days. However, the dissolved gas concentrations measured at the sampling locations from 27 April through 14 June averaged 112%, with a range from 103 to 122%; concentrations above 120% occurred upstream from RKm 179 from 11 May through 21 May.

External signs of GBD were infrequent. A low prevalence of GBD occurred in 6 of the 20 species that were examined. Mild signs of GBD (small blisters between fin rays) were observed in less than 1% of the juvenile chinook salmon (n = 1,648) and peamouth (n = 238), in 3% of the juvenile coho salmon (n = 711), and in 2% of the juvenile steelhead (n = 50) examined. Moderate to severe signs of GBD (large blisters on the body and exophthalmia) were observed in less than 1% of the sticklebacks (n = 906) and prickly sculpins (n = 174) examined. No evidence of GBD was observed in invertebrates collected from monitoring sites.

INTRODUCTION

In recent years, programs instituted to increase spill at Columbia and Snake River dams to increase survival of juvenile salmonids (*Oncorhynchus* spp.) have raised concern that the subsequent increase in dissolved gas levels of the water 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, dissolved gas levels in the Columbia and Snake Rivers often exceeded 110% of saturation (the criterion established by the U.S. Environmental Protection Agency, Washington State Department of Ecology, and Oregon State Department of Environmental Quality.)

Many studies on GBD and its effect on salmonids have been conducted. From 1968 to 1975, GBD in high-flow years contributed to high mortalities of the juvenile salmonids migrating from the Snake River (Ebel et al. 1975). The severity of GBD is dependent upon species, life stage, body size, level of dissolved gas, duration of exposure, water temperature, general physical condition of the fish, and swimming depth maintained (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 total dissolved gas (TDG) that salmonids can safely tolerate under natural conditions.

In 1970, when it became apparent that dissolved gas supersaturation of river water due to spill at dams was a serious problem for juvenile and adult stocks of 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) increase headwater storage to control flow during the spring freshet, 2) install additional turbines, 3) and install spillway flow deflectors ("flip-lips") to reduce air entrainment. As a result of these remedial measures, there was little evidence of GBD in salmonids in the late 1970s (Dawley 1986).

The current program of increased spill was implemented in the 1980s to improve passage of downstream migrating juvenile salmonids. As a result, diurnal fluctuations of dissolved gas supersaturation were created. In 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. However, he concluded that the impacts of dissolved gas supersaturation were minimal--probably because of the relatively short duration of high supersaturation conditions.

The effects of dissolved gas supersaturation on aquatic biota other than salmonids are not fully understood. Most research 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 (D'Aoust et al. 1976) that were capable of continuously recording dissolved gas saturation levels.

The objective of this study was to determine the biological effect of dissolved gas supersaturation on aquatic organisms in the Columbia River downstream from Bonneville Dam. In addition, a shallow-water bioassay was conducted to observe the effects of ambient supersaturated water from the reservoir of Bonneville Dam using resident fish species.

METHODS

Sampling

Sampling for the prevalence of GBD in salmonids, resident fish species, and invertebrates was conducted at 18 locations downstream from Bonneville Dam (River Kilometer (RKm) 228.5; River Mile 142) to RKm 62 (River Mile 38.5)) at least 3 times per week from 27 April to 14 June 1993. Figure 1 shows the study area and sample sites. A portion of the sampling was conducted concurrently with an ongoing juvenile salmonid stranding study.

Up to 100 juvenile salmonids and 100 individuals each of other species were sampled. We collected samples primarily using a 50-m variable-mesh beach seine that was 3.4-m deep. The beach seine was made up of four webbing-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

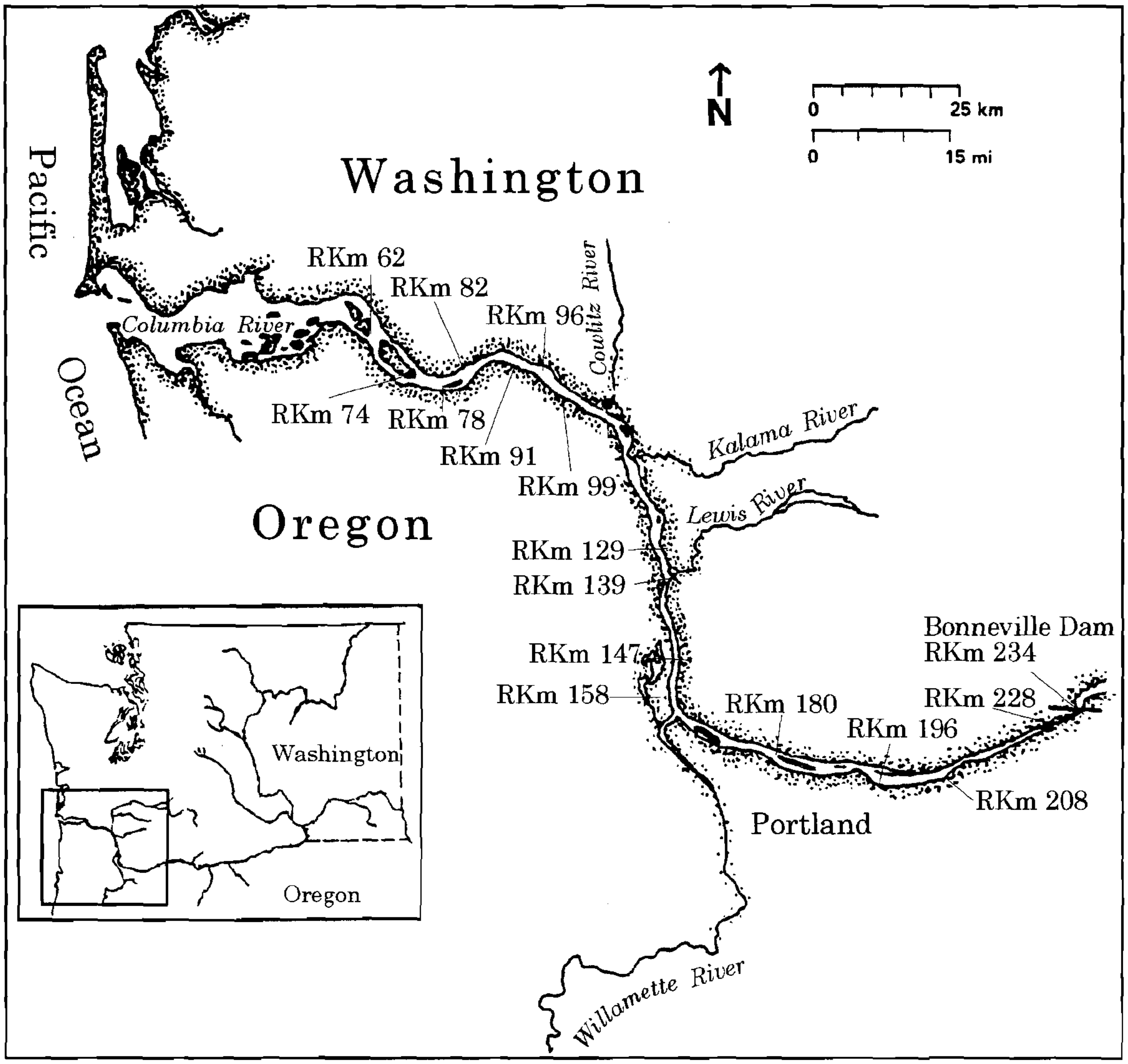

Figure 1. Sample sites for determining impacts of dissolved gas supersaturation on aquatic biota, Columbia River, downstream from Bonneville Dam, 1993.

the net, we anchored one end of the seine in dry sand and pulled the free end of the net off the beach in a wide arc with a 5-m boat, returning to the beach at an upstream point. At the Rooster Rock (RKm 208) and Lemon Island (RKm 179) sites, the current was too strong to pull the net upstream without capsizing the boat, so the net was pulled in a wide arc that ended at a downstream point.

In areas where it was not possible to use the beach seine, a 7.5-m 2-stick seine with 12.7-mm webbing was used. Two people pulled the seine upstream along the beach. Fish were collected from no deeper than 1 m with the 2-stick seine.

All fish were anesthetized and identified, and up to 50 individuals of each species were measured to the nearest millimeter and examined for marks. Up to 100 individuals of each species (including the 50 that were measured) were examined for exophthalmia and macroscopic gas bubbles in the fins and on the body surfaces. Specimens measuring less than 45-mm fork length were examined using a 10-power magnifying lens. All specimens were allowed to recover fully from the anesthetic prior to release.

Benthic invertebrates were collected from depths of up to 2 m using a Ponar bottom sampler. These samples were washed with water through a 0.5-mm screen, and all macroscopic invertebrates were sorted out. An attempt was made to use crayfish traps to capture crayfish (*Pacifastacus leniusculus*), but the areas where the traps could be deployed were in backwater sloughs which had much lower levels of dissolved gas and were not characteristic of the levels that existed in the main Columbia River.

Crayfish were examined for gas bubble emboli under the membrane between the carapace and the abdominal segments where Nebeker et al. (1976) reported signs in crayfish exposed to supersaturated water in the laboratory. Other invertebrates were examined for gas bubble emboli in the body fluids by viewing through the body wall. Asian clams (*Corbicula* spp.) were opened and were examined for conchiolin blisters in the shelf bordering the mantle as well as the outer layers of the mantle where Malouf et al. (1972) reported GBD signs in oysters and clams (*Mercenaria mercenaria*).

A 0.25-m diameter plankton net with 0.3-mm mesh was used to collect zooplankton samples from near the water surface. We found it extremely difficult to examine organisms in the field because of unfavorable weather conditions--it was impossible to view organisms with a 15-power microscope in a rocking boat, and on shore we encountered problems due to lack of adequate light and windy conditions.

Total dissolved gas (TDG) saturation and temperature were measured at the sampling locations with a tensiometer (Table 1). Additional dissolved gas data were accessed from the network maintained by the COE North Pacific Division Water Quality Section, in order to monitor the saturation levels at Bonneville Dam and at Warrendale, Oregon, 8 km downstream from Bonneville Dam.

Table 1. Temperature and dissolved gas measurements taken at and near sampling sites on the Columbia River downstream from Bonneville Dam, 1993.

Date	Site	Location	River Km	Time	Temp. °C	Total gas pres.	Saturation %
27 Apr	Fish Trap Shoals, OR	shore	148	1342	13.7	845	110
27 Apr	Fish Trap Shoals, OR	shore	148	1542	13.7	829	108
28 Apr	County Line Park, WA	shore	83	1155	10.4	818	107
29 Apr	Puget Island, WA	shore	74	1120	11.2	817	107
30 Apr	Hump Island, WA	shore	96	1307	11.8	817	107
5 May	Rainier Landing, OR	dock	109	1048	12.1	819	107
5 May	Rooster Rock, OR	shore	209	1500	14.7	877	114
5 May	Rooster Rock, OR	channel	209	1525	12.2	830	109
6 May	Austin Point, WA	shore	140	1140	10.5	809	106
7 May	Hoagy's Bar, OR	channel	92	1128	12.1	813	107
7 May	Hoagy's Bar, OR	shore	92	1148	12.4	810	106
10 May	Washougal Port Dock, WA	dock	196	1110	12.3	846	111
10 May	Hamilton Island, WA	dock	232	1219	12.3	813	106
10 May	Washougal Port Dock, WA	dock	196	1314	12.7	900	118
10 May	Vancouver City Park, WA	dock	171	1437	13.1	831	109
10 May	Kalama, WA	dock	120	1555	12.9	840	110
11 May	Washougal Port Dock, WA	dock	196	1056	12.3	883	115
11 May	Warrendale, OR	dock	227	1230	12.3	869	114
11 May	Corbett, OR	shore	204	1328	12.5	922	121
11 May	Washougal Port Dock, WA	dock	196	1422	12.5	949	124
11 May	Vancouver City Park, WA	dock	171	1508	13.1	842	110
12 May	Martin's Island, WA	channel	129	1234	12.7	859	112
12 May	Martin's Island, WA	shore	129	1405	13.5	869	114
13 May	Rooster Rock, OR	channel	209	855	12.6	899	118
13 May	Rooster Rock, OR	shore	209	1024	13.4	882	116
13 May	Lemon Island, OR	channel	180	1244	14.3	864	113
13 May	Lemon Island, OR	shore	180	1350	14.1	861	113
14 May	Tenasillahe Island, OR	channel	62	1006	13.3	854	112
14 May	Tenasillahe Island, OR	channel	62	1306	14.3	864	112
17 May	Rooster Rock ,OR	channel	209	853	13.7	878	115
17 May	Rooster Rock, OR	shore	209	1015	14.2	902	118
18 May	Puget Island, WA	channel	74	955	14.2	859	113
18 May	Puget Island, WA	channel	74	1207	15.1	866	133
19 May	Rooster Rock, OR	channel	209	827	16.4	936	123
19 May	Rooster Rock, OR	shore	209	932	14.8	899	118
19 May	Rooster Rock, OR	channel	209	1002	13.9	932	122
19 May	Rooster Rock, OR	shore	209	1114	14.4	925	121
19 May	Lemon Island, OR	channel	180	1438	14.2	927	122
20 May	Fish Trap Shoals, OR	channel	148	910	14.5	895	117
20 May	Fish Trap Shoals, OR	channel	148	1010	15.5	886	116
21 May	Rooster Rock, OR	channel	209	745	14.0	929	122
21 May	Rooster Rock, OR	shore	209	838	14.1	894	118
21 May	Lemon Island, OR	channel	180	1245	14.2	922	121
21 May	Lemon Island, OR	channel	180	1336	14.4	921	121
22 May	Puget Island, WA	channel	74	1040	14.4	882	116
22 May	Puget Island, WA	shore	74	1314	15.2	887	116
24 May	Rooster Rock, OR	channel	209	1337	14.5	908	119
24 May	Rooster Rock, OR	shore	209	1422	14.8	889	117
1 Jun	Bonneville Dam, WA	forebay	234	1220	16.4	866	117
1 Jun	Beacon Rock, WA	shore	228	1550	16.5	890	116
2 Jun	Hoagy's Bar, OR	shore	92	1921		815	107
3 Jun	Bonneville Dam, WA	forebay	234	1406	15.7	853	112
3 Jun	Beacon Rock, WA	shore	228	1620	16.2	873	114
4 Jun	Wallace Island, WA	shore	79	1147	15.5	850	112
4 Jun	Wallace Island, WA	shore	79	1358	15.5	850	112
7 Jun	Lwr. End Lord Isl., OR	shore	100	1159		822	108
8 Jun	Lewis & Clark St. Park, OR	shore	197	1532		885	116
9 Jun	Hump Island, WA	shore	96	1954	15.0	836	110
9 Jun	Puget Island, WA	shore	74	1023	15.0	833	110
10 Jun	Deer Island, OR	shore	129	1515		836	110
11 Jun	Westport Slough, OR	shore	116	1330		815	107
14 Jun	Marshall's Beach, OR	shore	157	1357		781	103
14 Jun	Mathew's Point, OR	shore	163	1438		790	104

Live-Cage Study

Resident species were collected on 28 May immediately upstream from the entrance to Westport Slough (RKm 72) for a live-cage study at Bonneville Dam. The purpose of this live-cage study was to attempt to induce GBD in resident fish species held in the supersaturated water at Bonneville Dam by restricting them to shallow water. Up to this point in the study, external signs of GBD had not been observed on any of the resident species examined. An attempt was made to collect up to 100 individuals of each species. Because of the low beach seine catch of resident species other than threespine sticklebacks (*Gasterosteus aculeatus*), beach seining efforts were discontinued after four sets. Of the 4 peamouth (*Mylocheilus caurinus*), 14 starry flounder (*Platichthys stellatus*) and 100 threespine stickleback collected, none showed signs of GBD. The fish were transported to Bonneville Dam in a 120-L container with oxygenated water. At Bonneville Dam, the fish were transferred to a net-pen suspended in a raceway at the juvenile fish processing facility. The net-pen was restricted to a depth of approximately 15 cm in the raceway, which was constantly supplied with river water from Bonneville Dam forebay. The fish were anesthetized and examined for signs of GBD after being held for 4 days and again after 6 days.

A tensiometer was used to measure dissolved gas levels in the raceway to compare with the dissolved gas levels measured at the same time with the monitor maintained by the COE in Bonneville Dam forebay. The readings were within 1% of each other and were within the range of expected variability for measurements made by the tensiometer (Brian D'Aoust, 1993, Common Sensing Equipment, pers. commun.).

RESULTS

Three species of invertebrates and 17 species of fish were collected and identified during the study (Table 2). The invertebrates examined were Asian clams (*Corbicula* spp.), crayfish, and dragonfly larvae (*Gomphus* spp.). The 2,425 juvenile salmonids examined included, in descending order of abundance, chinook salmon, coho salmon (*O. kisutch*), steelhead (*O. mykiss*), cutthroat trout (*O. clarki*), chum salmon (*O. keta*), and sockeye salmon (*O. nerka*). The 1,522 resident fish included, in descending order of abundance, threespine stickleback, peamouth, prickly sculpin (*Cottus asper*), starry flounder, largescale sucker (*Catostomus macrocheilus*), northern squawfish (*Ptychocheilus oregonensis*), banded killifish (*Fundulus diaphanus*), redside shiner (*Richardsonius balteatus*), Pacific staghorn sculpin (*Leptocottus armatus*), and common carp (*Cyprinus carpio*). In addition to these species, 111 juvenile American shad (*Alosa sapidissima*) were collected. A total of 66 invertebrates and 4,058 fish were examined for external signs of GBD.

Among the fish examined, juvenile salmonids had the highest prevalence of GBD. Overall, juvenile coho salmon had the highest prevalence of GBD at 3% (21/711), with steelhead next at 2% (1/50). The lowest prevalences of GBD were observed in chinook

Table 2. Prevalence of gas bubble disease by species for organisms collected on the Columbia River downstream from Bonneville Dam from 27 April through 14 June, 1993.

Species	Scientific name	Sample (n)	Prevalence of signs of gas bubble disease (%)
Asian clam	*Corbicula* spp.	23	0
Common carp	*Cyprinus carpio*	2	0
Chinook salmon	*Oncorhynchus tshawytscha*	1,657	0.1
Chum salmon	*Oncorhynchus keta*	1	0
Coho salmon	*Oncorhynchus kisutch*	711	3.0
Crayfish	*Pacifastacus leniusculus*	36	0
Cutthroat trout	*Oncorhynchus clarki*	5	0
Dragonfly larvae	*Gomphus* spp.	7	0
Killifish	*Fundulus diaphanus*	13	0
Largescale sucker	*Catostomus macrocheilus*	40	0
Pacific staghorn sculpin	*Leptocottus armatus*	4	0
Peamouth	*Mylocheilus caurinus*	238	0.4
Prickly sculpin	*Cottus asper*	174	0.6
Redside shiner	*Richardsonius balteatus*	8	0
American shad	*Alosa sapidissima*	111	0
Sockeye salmon	*Oncorhynchus nerka*	1	0
Northern squawfish	*Ptychocheilus oregonensis*	20	0
Starry flounder	*Platichthys stellatus*	117	0
Steelhead	*Oncorhynchus mykiss*	50	2.0
Threespine stickleback	*Gasterosteus aculeatus*	906	0.2
Total invertebrates		66	0
Total fish		4,058	0.7
Total salmonids		2,425	1.0
Total non-salmonids		1,633	0.2
Total resident fish		1,522	0.3

salmon at 0.1% (2/1657), and cutthroat trout, sockeye salmon, and chum salmon at 0% (5, 1, and 1 examined, respectively). The signs observed in these fish were cutaneous bubbles between the rays of the anal and/or caudal fins. Daily prevalence of signs of GBD was similar to that reported by personnel from the smolt monitoring program at Bonneville Dam (Columbia Basin Fish and Wildlife Authority 1993). For the smolt monitoring program, the highest prevalences of signs of GBD observed were: 8% for wild steelhead on 21 May, 11% for hatchery steelhead on 28 May, 2.7% for coho salmon on 25 May, 0.2% on subyearling chinook salmon on 21 May, and 0.4 to 0.7% of the sockeye salmon sampled on 4 consecutive days from 26 May through 29 May (from daily samples of several hundred fish). Downstream from Bonneville Dam, the highest prevalences of signs of GBD observed were: 1 of 5 (20%) steelhead (no distinction between wild and hatchery) on 25 May, 13 of 17 (76.5%) coho salmon on 21 May, 1 of 68 (1.5%) on 21 May and 1 of 102 (1%) on 22 May for subyearling chinook salmon, and none on 1 each sockeye salmon and chum salmon. At Bonneville Dam, during the period when the most signs of GBD were observed, the average daily percent dissolved gas saturation level was above 120%, with a maximum of 125%. For the period that the COE monitor at Warrendale, Oregon was operating, the average daily percent dissolved gas saturation level exceeded 120% during the same period when most of the signs of GBD were observed.

Few signs of GBD were observed in prickly sculpin (0.6%; 1/174), peamouth (0.4%; 1/238) and threespine stickleback (0.2%; 2/906). The peamouth had a small cutaneous bubble in the anal fin; the prickly sculpin had unilateral exophthalmia; the threespine sticklebacks had large bubbles that extended from below the dorsal fin to the caudal peduncle, above the lateral line. Photographs attempting to illustrate signs of GBD in threespine sticklebacks were unsatisfactory. Figure 2 illustrates the size of the bubbles observed on the threespine sticklebacks. Signs of GBD were not observed in the three species of invertebrates that we collected.

Signs of GBD were first observed in fish on 19 May at Rooster Rock when the TDG measured 121%. The daily average dissolved gas saturation level at Bonneville Dam, 26 Km upstream from Rooster Rock, was 122%. According to the hourly TDG monitoring data supplied by the COE, the TDG measured at Bonneville Dam forebay had exceeded 120% since 1300 h on 17 May and ranged from 120.3% to 123.2%. The hourly TDG levels measured at Warrendale, 8 Km downstream from Bonneville Dam and 18 Km upstream from Rooster Rock, exceeded 120% at 1500 h on 17 May, and ranged from 122.2% to 123.8% between 17 and 19 May. From 19 May through 27 May, the daily average TDG at Bonneville Dam was between 121 and 123%, ranging from 119.5 to 124.7%. The Warrendale station did not operate between 19 May and 4 June. The last time that signs of GBD were observed was on 9 June when the TDG was 110%.

Throughout the period 19 May through 9 June, the 2 juvenile chinook salmon, 20 juvenile coho salmon, 1 juvenile steelhead, and 1 peamouth that exhibited signs of GBD were collected at sites from Rooster Rock downstream to Hump Island (RKm 96). The

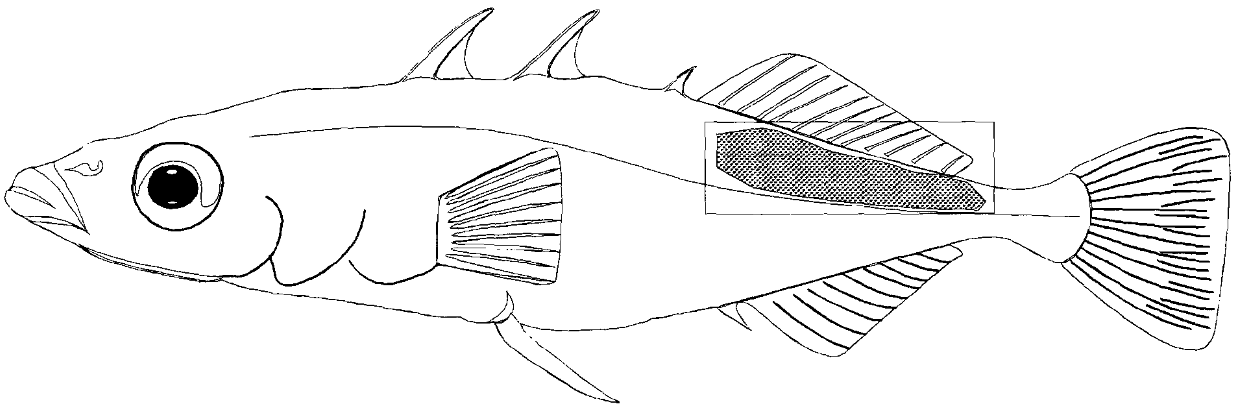

Figure 2. Relative size and location of gas bubbles observed on two threespine sticklebacks captured in the Columbia River, 1 June 1993.

prickly sculpin and two threespine sticklebacks that exhibited GBD signs were collected at Beacon Rock (RKm 232), the farthest upstream collection location and where the TDG measured 116%. The number of fish observed with signs of GBD and the TDG measurements made during the sampling times are shown in Figure 3 and Appendix Table 1.

From 19 May through 9 June, the highest TDG level measured at a sampling site was 122% at Rooster Rock, while the lowest was 107% at Hoagy's Bar (RKm 91). All of the fish with signs of GBD were captured upstream from Hump Island.

The size ranges of the 17 species of fish caught with the beach seine and the 9 species of fish caught with 2-stick seine are shown in Table 3. Chinook salmon were the only salmonids caught with the 2-stick seine. Generally, the fish caught with the 2-stick seine were smaller than those caught with the beach seine. The difference in sizes of fish caught with the 2-stick seine versus the beach seine are shown for juvenile chinook salmon in Figure 4, for peamouth in Figure 5, and for threespine sticklebacks in Figure 6. Length-frequency distributions for fish caught with the two types of gear were graphed only for species where more than 200 individuals were captured with both types of gear combined.

Levels of dissolved gas throughout the lower Columbia River were monitored by the COE at established locations. The COE intended to install additional TDG monitoring stations at Washougal and Kalama, Washington, and Wauna, Oregon, but unfortunately, these stations were not operating during this

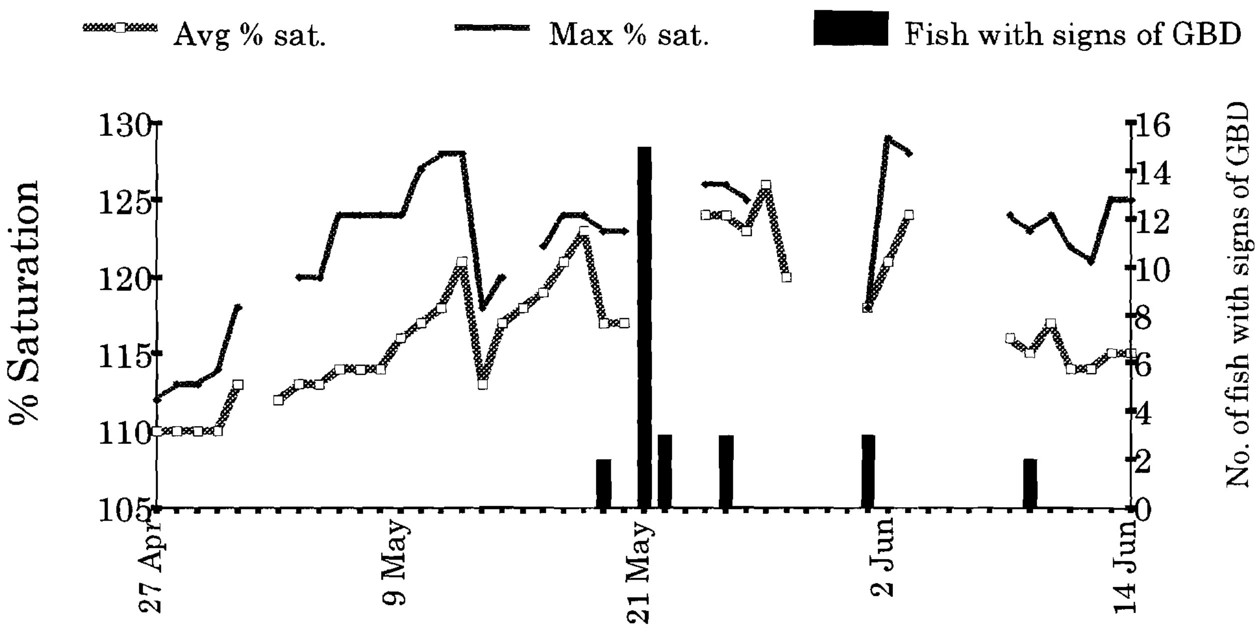

Figure 3. Daily average and maximum percent dissolved gas saturation measured at Warrendale, Oregon and the number of fish observed with signs of gas bubble disease (GBD) during sampling downstream from Bonneville Dam, 1993.

Table 3. Size range (mm) of all fish collected for examination for signs of gas bubble disease downstream from Bonneville Dam from 27 April through 14 June 1993. Fork lengths were measured for salmonids. For all other fish, total lengths were measured.

Species	Beach seine			Stick seine			Total no. of fish measured	Overall size range
	Range (mm)	No. measured	Total measured (%)	Range (mm)	No. measured	Total measured (%)		
Common carp	580	1	50.0	29	1	50.0	2	29-580
Chinook salmon	38-190	1,076	91.7	36-65	97	8.3	1,173	36-190
Chum salmon	61	1	100.0	--*	--	--	1	61
Coho salmon	104-197	711	100.0	--	--	--	711	104-197
Cutthroat trout	176-233	5	100.0	--	--	--	5	176-233
Killifish	70	1	7.8	32-80	12	92.2	13	70
Largescale sucker	146-530	39	97.5	57	1	2.5	40	57-530
Pacific staghorn sculpin	52-71	4	100.0	--	--	--	4	52-71
Peamouth	48-324	202	86.0	21-53	33	14.0	235	21-324
Prickly sculpin	35-175	34	21.4	46-135	125	78.6	159	35-175
Redsided shiner	122-135	2	25.0	37-46	6	75.0	8	37-135
American shad	105-172	101	100.0	--	--	--	101	105-172
Sockeye salmon	91	1	100.0	--	--	--	1	91
Northern squawfish	136-459	19	100.0	--	--	--	19	136-459
Starry flounder	61-170	115	98.3	96-98	2	1.7	117	61-170
Steelhead	166-266	48	100.0	--	--	--	48	166-266
Threespine stickleback	44-70	377	84.5	19-72	69	15.5	446	19-72

* None captured.

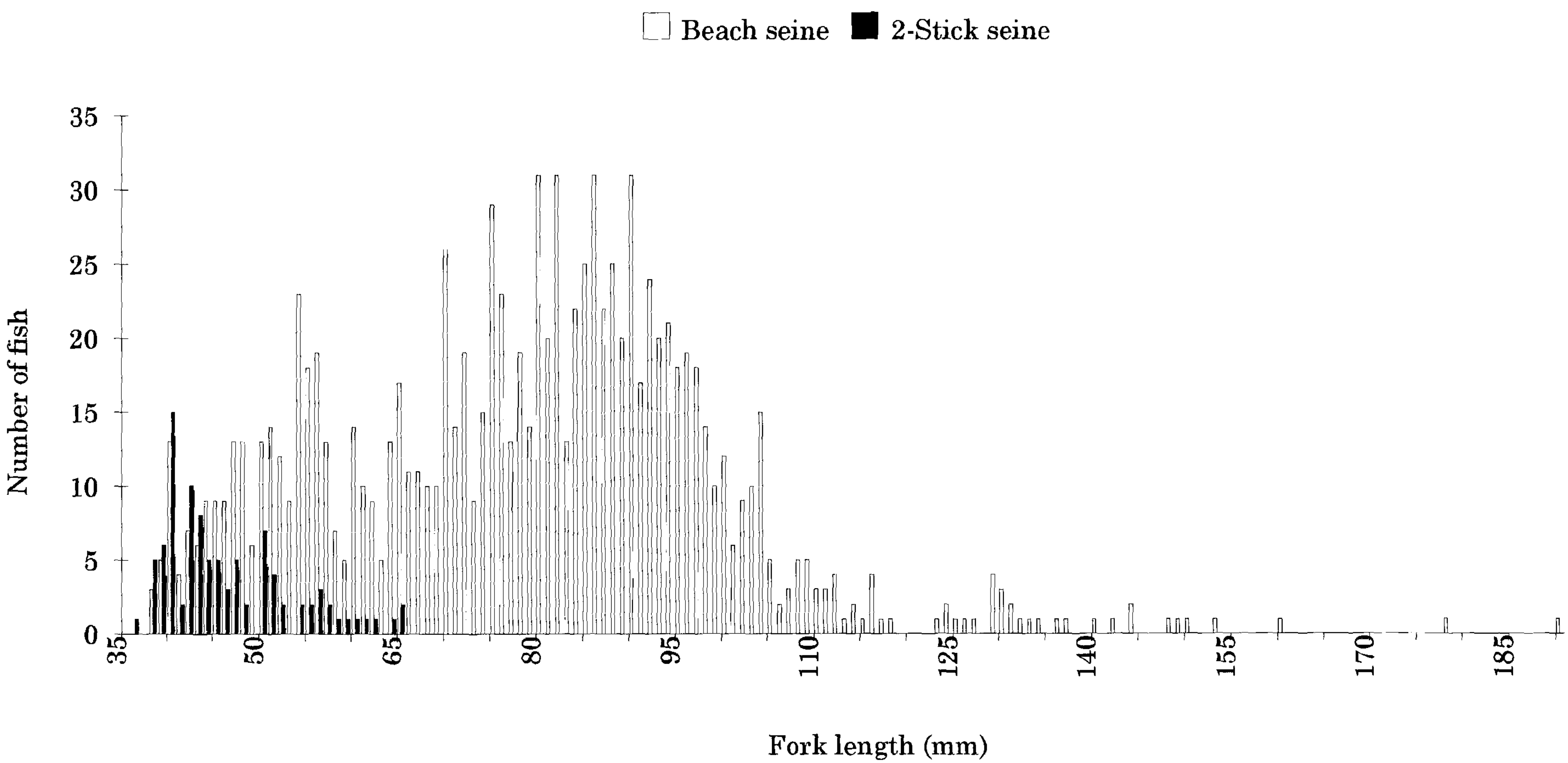

Figure 4. Length-frequency distribution of juvenile chinook salmon caught with a beach seine versus a 2-stick seine in the Columbia River downstream from Bonneville Dam, 1993.

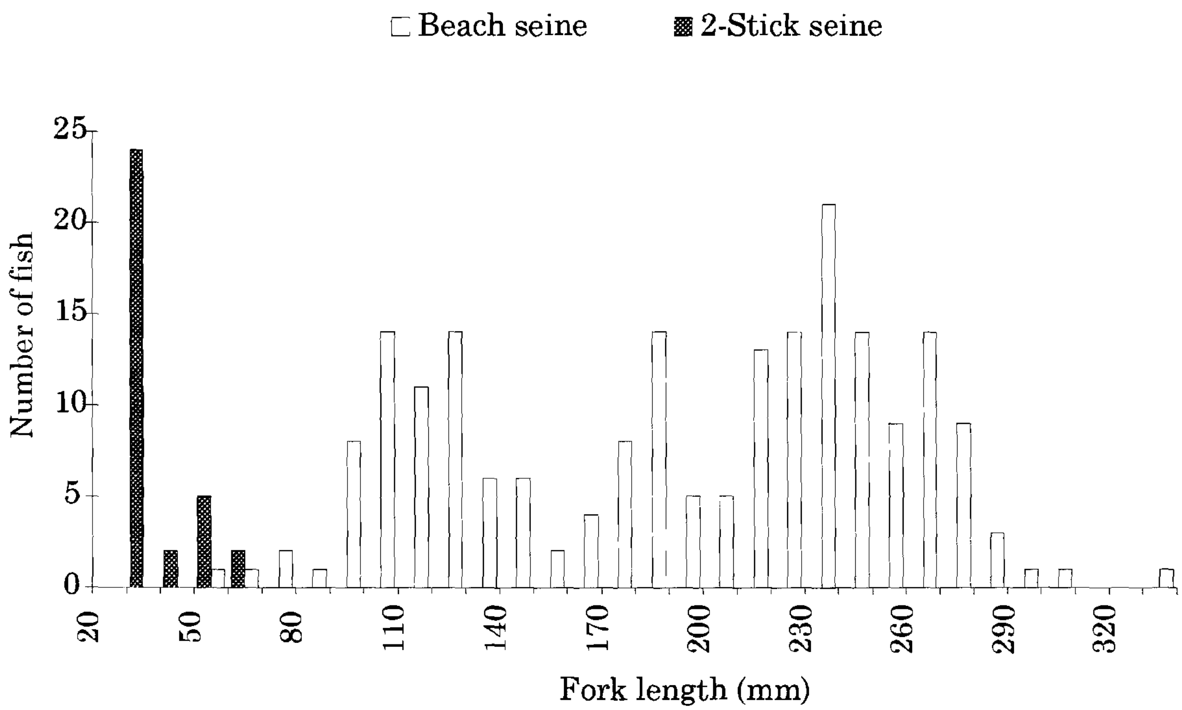

Figure 5. Length-frequency distribution of peamouth caught with a beach seine versus a 2-stick seine in the Columbia River downstream from Bonneville Dam, 1993.

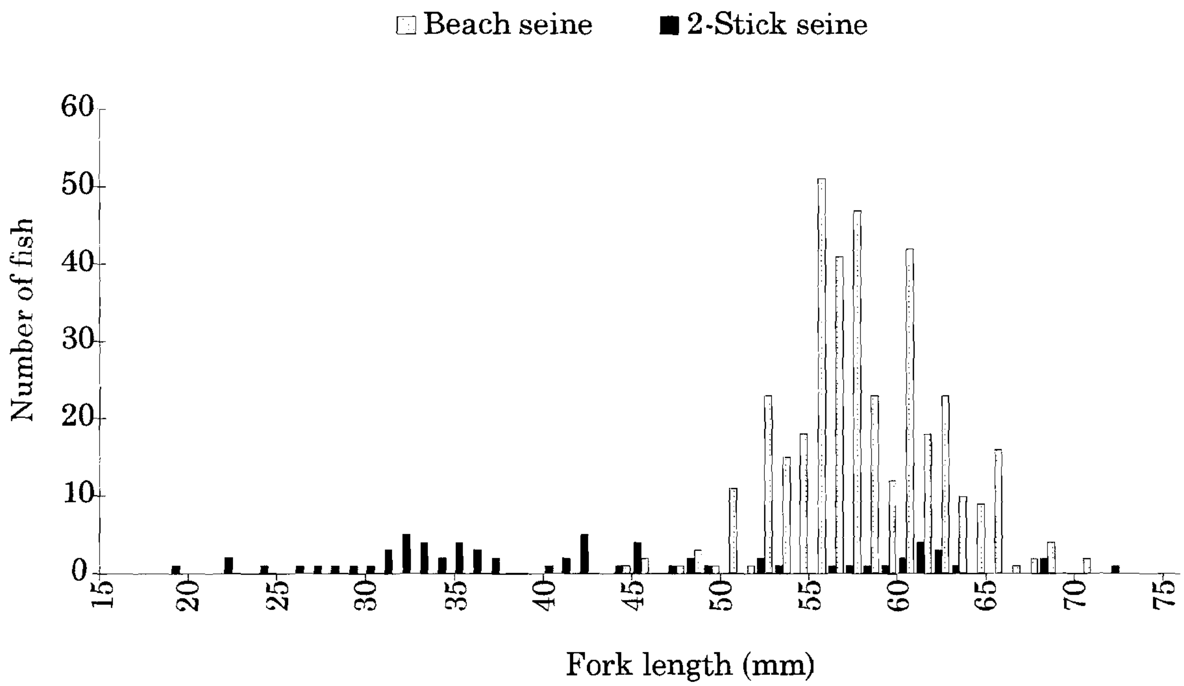

Figure 6. Length-frequency distribution of threespine sticklebacks caught with a beach seine versus a 2-stick seine in the Columbia River downstream from Bonneville Dam, 1993.

study. The only monitoring station downstream from Bonneville Dam was at Warrendale, and this station did not operate between 19 May and 4 June, which was during a critical time period for this study. National Marine Fisheries Service (NMFS) personnel installed a monitor at Warrendale on 24 May and were able to obtain TDG data intermittently. The daily mean and maximum TDG values from the COE monitoring stations at Bonneville Dam and Warrendale, Oregon are summarized in Table 4.

Hourly spill at Bonneville Dam and dissolved gas levels at Warrendale are shown in Appendix Figures 1 and 2. The spill regime prevailing during this study, with increased spill at night, resulted in diel fluctuation in dissolved gas levels, rather than continuous high levels of dissolved gas supersaturation. During the time period that the Warrendale monitor operated, the dissolved gas saturation levels there lagged behind the increase and decrease of spill levels at Bonneville Dam by approximately 2 hours. Figure 7 shows this diel fluctuation over a 1-week period.

Results of the live cage experiment at Bonneville Dam are listed in Table 5, and TDG readings (percent saturation) are listed in Table 4. Two of the four peamouth died after 4 days, a third died after 6 days, but none showed signs of GBD, and cause of death was not determined. However, the peamouth that died after 6 days had a severe fungal infection and eroded fins. Five of the starry flounder died after 4 days, and another two died after 6 days. Four of the survivors showed signs of GBD at the end of 6 days. Signs of GBD observed in the four starry

Table 4. Daily mean and maximum dissolved gas saturation values at Bonneville Dam forebay and Warrendale monitoring sites from 26 May through 8 June 1993. (Source of data: Fish Passage Center; Warrendale data supplied by monitor installed by NMFS.)

	Bonneville Dam		Warrendale	
Date	Mean	Maximum	Mean	Maximum
27 Apr	103	103	110	112
28 Apr	103	103	110	113
29 Apr	102	103	110	113
30 Apr	103	103	110	114
1 May	103	103	113	118
2 May	--*	--	--	--
3 May	105	107	112	--
4 May	103	104	113	120
5 May	103	106	113	120
6 May	104	106	114	124
7 May	105	108	114	124
8 May	104	106	114	124
9 May	105	107	116	124
10 May	108	111	117	127
11 May	111	114	118	128
12 May	109	115	121	128
13 May	110	114	113	118
14 May	115	116	117	120
15 May	117	--	118	--
16 May	118	119	119	122
17 May	120	121	121	124
18 May	122	123	123	124
19 May	122	123	117	123
20 May	122	124	117	123
21 May	122	125	--	--
22 May	121	123	--	--
23 May	122	122	--	--
24 May	123	125	124	126
25 May	122	124	124	126
26 May	121	--	123	125
27 May	121	--	126	--
28 May	119	120	120	--
29 May	120	121	--	--
30 May	119	123	--	--
31 May	118	120	--	--

Table 4. Continued.

Date	Bonneville Dam		Warrendale	
	Mean	Maximum	Mean	Maximum
1 Jun	116	118	118	118
2 Jun	116	118	121	129
3 Jun	115	116	124	128
4 Jun	116	117	117	118
5 Jun	117	120	119	125
6 Jun	115	118	118	123
7 Jun	110	112	115	123
8 Jun	107	108	116	124
9 Jun	109	112	115	123
10 Jun	110	112	103	124
11 Jun	108	112	102	122
12 Jun	107	108	114	121
13 Jun	108	112	115	125
14 Jun	108	112	115	125

* No data available.

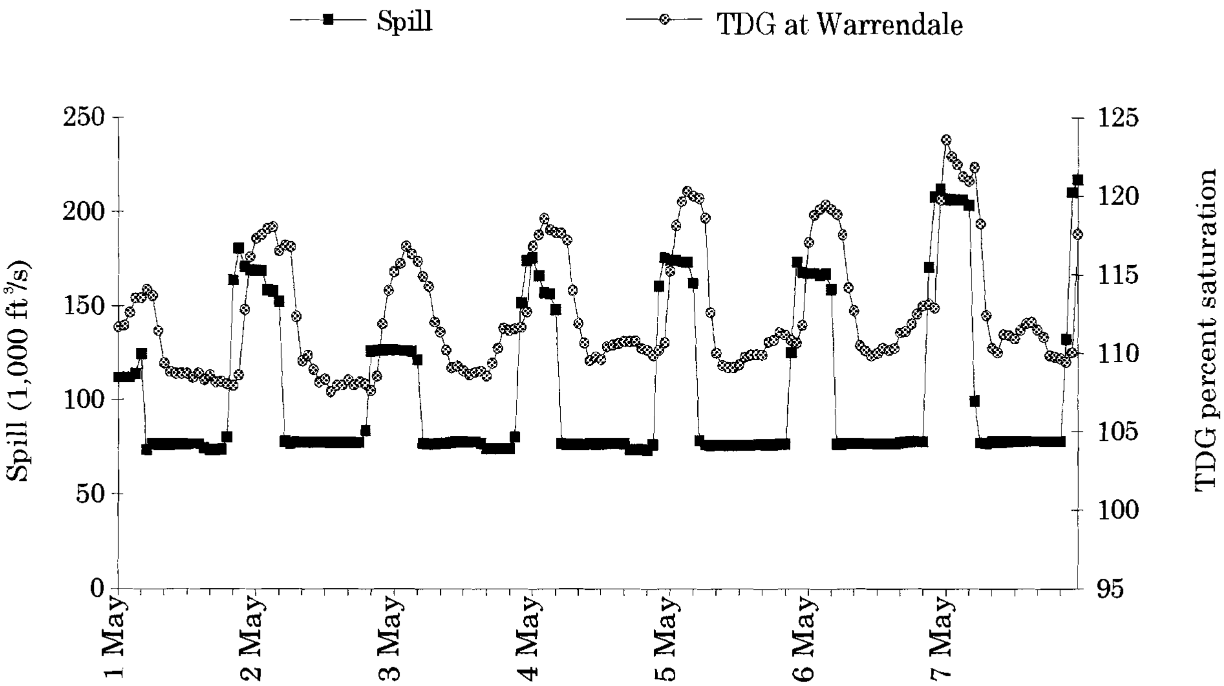

Figure 7. Hourly spill at Bonneville Dam and total dissolved gas (TDG) saturation values at Warrendale, Oregon, Columbia River, 1993. By convention, English units were used for river flow volumes (1,000 ft^3/s = 28.3 m^3/s).

Table 5. Prevalence of gas bubble disease and mortality of fish after being held 4 days and 6 days in a live cage at Bonneville Dam juvenile fish processing facility from 28 May through 3 June 1993.

Days held		4 days		6 days	
Species	No.	No. w/ GBD	No. mortality	No. w/ GBD	No. mortality
Peamouth	4	0	2	0	1
Starry flounder	14	4	5	4	2
Threespine stickleback	100	4	2	7	10

flounder included numerous bubbles in the caudal fins, dorsal fins, and ventral fins. Similar signs of GBD were observed in the dead starry flounder. Two of the 100 threespine sticklebacks died after 4 days, and 10 died after 6 days. Four showed signs of GBD after 4 days, and seven showed signs after 6 days. The signs of GBD observed in the threespine sticklebacks were small bubbles in the caudal fins. The dead threespine sticklebacks did not show external signs of GBD. We did not dissect any of the dead fish to determine if there were internal signs of GBD.

DISCUSSION

Although little evidence of external signs of GBD was observed during this study, it is not certain whether dissolved gas supersaturation resulted in adverse biological effects, because only living fish were captured and observed. The results of studies conducted to evaluate the effects of GBD on the lateral line function in salmonids (Schiewe and Weber 1976) indicated that, as gas emboli formed in the lateral line of stressed fish, the ability to respond to stimuli was diminished or absent--results which suggested that exposure to sublethal levels of dissolved gas could increase the susceptibility of fish to predation. Another study that examined the sublethal effects of GBD (Schiewe 1974), indicated that fish exhibited decreased swimming capability immediately following exposure to dissolved gas concentrations ranging from 106 to 120% of saturation. Weitkamp (1976) reported that mortalities of juvenile chinook salmon that were held to recover from GBD were apparently caused by severe fungal infections indirectly resulting from GBD. These fungal infections had progressed to the point that the caudal fin was completely eroded in all of the dead fish. In our live-cage experiment conducted at Bonneville Dam, one of the peamouth that died after being held in gas supersaturated water for 6 days showed signs of a severe fungal infection, and its fins were eroded. On 1 June at Beacon Rock, 1 of the 14 threespine sticklebacks collected had an eroded caudal fin, and the 1 largescale sucker collected had an eroded caudal fin. We did not observe eroded fins in fish collected at any of the other sampling locations.

The measurements of dissolved gas levels made concurrently during sampling for signs of GBD in fish and invertebrates downstream from Bonneville Dam were important for two reasons. First, there was no other monitoring program in place during this study. Second, the maximum dissolved gas saturation criterion of 110%, established by the U.S. Environmental Protection Agency, Washington State Department of Ecology, and Oregon State Department of Environmental Quality was exceeded on at least 37 of the 49 days from 27 April through 14 June.

When the Warrendale TDG monitor was functioning, the daily mean dissolved gas saturation values were from 1 to 12% higher than those measured at Bonneville Dam, which resulted in saturation levels ranging from 110 to 126%. Daily mean dissolved gas saturation at Warrendale was above 120% on 9 days, and reached a maximum of 128% on 4 days. Ebel et al. (1975) reported that signs of GBD in migrating salmonids and resident fish were apparent when dissolved gas saturation levels were 125% or greater for a period of several days. The monitor at Warrendale malfunctioned during a critical part of the study period (from 19 May through 4 June 1993), so we have no information regarding dissolved gas levels at Warrendale during that time.

As noted above, the 2-stick seine captured smaller fish than the beach seine. The 2-stick seine may have caught smaller fish than the beach seine because of the smaller mesh size in the 2-stick seine, the more shallow depths fished, or the difference in substrates between the areas where the beach seine and the 2-stick seine were deployed. The difference in the size of fish collected with the two types of gear is of concern because the results of several experiments indicated that as salmonids grow, their tolerance to high levels of dissolved gas decreases (Dawley et al. 1976, Nebeker et al. 1978, Krise 1993). Dell et al. (1974) observed that large northern squawfish, suckers (*Catostomus* spp.), and whitefish (*Prosopium williamsoni*) tended to be relatively more afflicted by GBD than the small fish. Crunkilton et al. (1980) observed that in several species of nonsalmonid fish, larger fish were more susceptible to GBD than smaller fish. The 2-stick seine was a valuable collection technique, however, because it could be deployed in areas where resident species were more common and where it was not possible to deploy the beach seine.

Reduction of high levels of dissolved gas in the Columbia River occurs when water of lower saturation from the Willamette River mixes with the Columbia River. The Willamette River flow[1] was highest relative to the Columbia River flow on 27 April (45.0 kcfs compared to 168.7 kcfs, respectively), and lowest on 17 May when flow was 25.6 kcfs compared to 381.5 kcfs in the Columbia River. This resulted in a reduction of the Willamette River contribution to the total Columbia River from 27 to 7% (Fig. 8). The dissolved gas levels in the Willamette River are not currently monitored, but are presumed to have been near saturation at these low flow volumes.

Measurements at our sampling sites indicated that dissolved gas levels in the Columbia River below the confluence with the Willamette River were lower than those measured by the COE monitoring system at Bonneville Dam (Tables 1 and 4). The COE had not installed total dissolved gas monitors at Washougal and Kalama, Washington or at Wauna, Oregon (i.e., at any sites downstream from Warrendale) until after this study terminated, so we have no record of dissolved gas levels farther downstream. We also could not ascertain to what extent there was dilution or dissipation of dissolved gas farther downstream.

Signs of GBD were observed in resident fish species at only two sampling locations: Beacon Rock (RKm 232) and Puget Island (RKm 74). One reason for the low prevalence of GBD in resident

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[1] The U.S. Geological Survey supplied flow information for the Willamette River at Salem, Oregon because effects of tidal influence at Portland had yet to be confirmed.

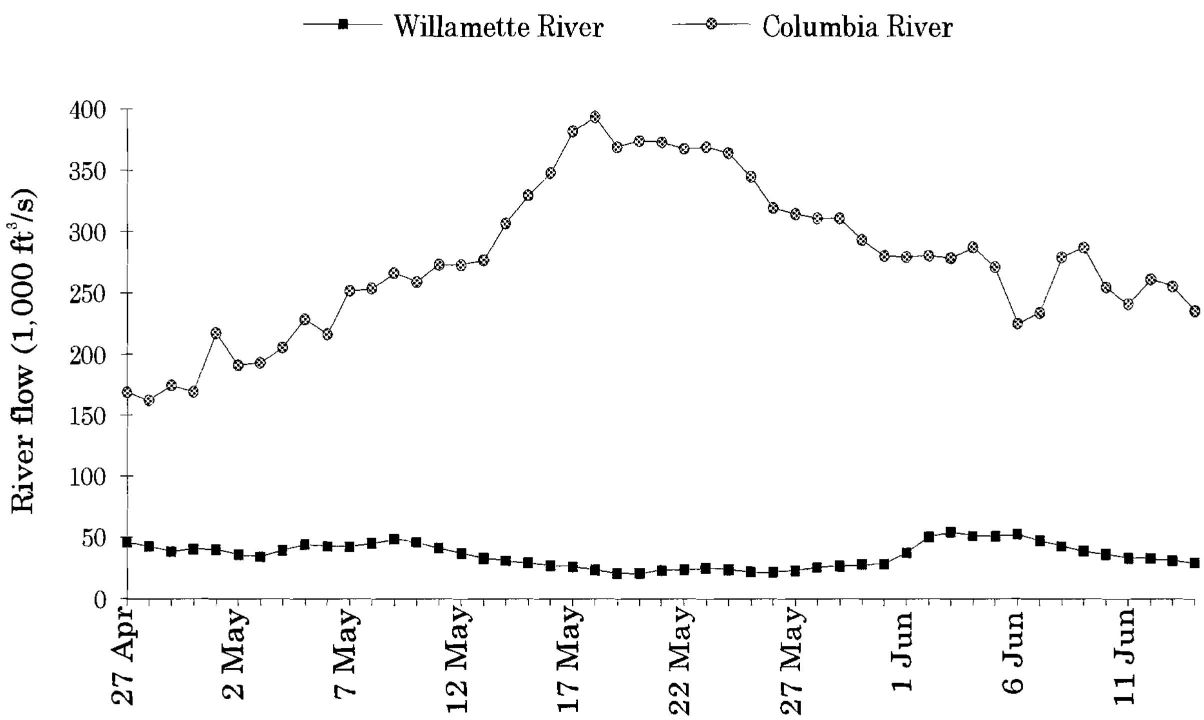

Figure 8. Daily average flow for Columbia and Willamette Rivers, 1993. By convention, English units were used for river flow volumes (1,000 ft^3/s = 28.3 m^3/s).

species may be that most of our sampling was conducted below the confluence of the Columbia and Willamette Rivers, where dissolved gas levels were lower than upstream. During this study, dissolved gas levels above 120% of saturation were measured upstream from Lemon Island (RKm 179) from 19 May through 25 May, with the highest dissolved gas level of 122% measured at Rooster Rock (RKm 208) on 25 May. During the 1974 spill season in the Mid-Columbia River reservoirs, Dell et al. (1974) found that 10.6% of the 29,273 resident fish examined showed signs of GBD. Dell et al. (1974) reported that the saturation levels were above 120% from 22 May through 2 August, and were above 125% from 12 June through 4 July. The lower dissolved gas levels observed and the shorter duration of high dissolved gas levels during 1993 may be the reason why a lower prevalence of GBD was observed in resident species during our study than during the study conducted in 1974.

No signs of GBD were observed in the three species of invertebrates that were collected during this study. Since all three species are benthic or epibenthic organisms, water depth may have provided hydrostatic compensation for the levels of dissolved gas that occurred. Nebeker et al. (1976) reported that western crayfish held at a depth of 60 cm for 30 days in the laboratory in 120% supersaturated water were unaffected. The dissolved gas levels measured where we collected crayfish were 120% or less. No laboratory studies have been conducted to determine the effects of dissolved gas supersaturation on Asian clams or dragonfly larvae, and to date there have been no reported observations of GBD in these species of invertebrates.

CONCLUSIONS

A low prevalence of GBD was observed among the 17 species of fish and invertebrates collected during this study. Because of the malfunctioning COE dissolved gas monitor at Warrendale, Oregon during the critical period of peak spill, we were unable to correlate exposure to particular levels of dissolved gas with development of signs of GBD in fish and invertebrates. Since we cannot extrapolate from observations of external signs of GBD to potential lethal and sublethal effects of exposure to dissolved gas supersaturation levels over time, larger-scale live-cage studies would be useful. Lethal concentrations of dissolved gas may occur in certain areas of the Columbia River Basin under conditions of high flow and spill, so a greater knowledge of the tolerance of fish and invertebrates to high levels of dissolved gas is important for management of any spill program. Consistent with an ecosystem approach, it is important to consider the effects of dissolved gas supersaturation on other organisms in the Columbia River ecosystem, as well as its effects on salmon.

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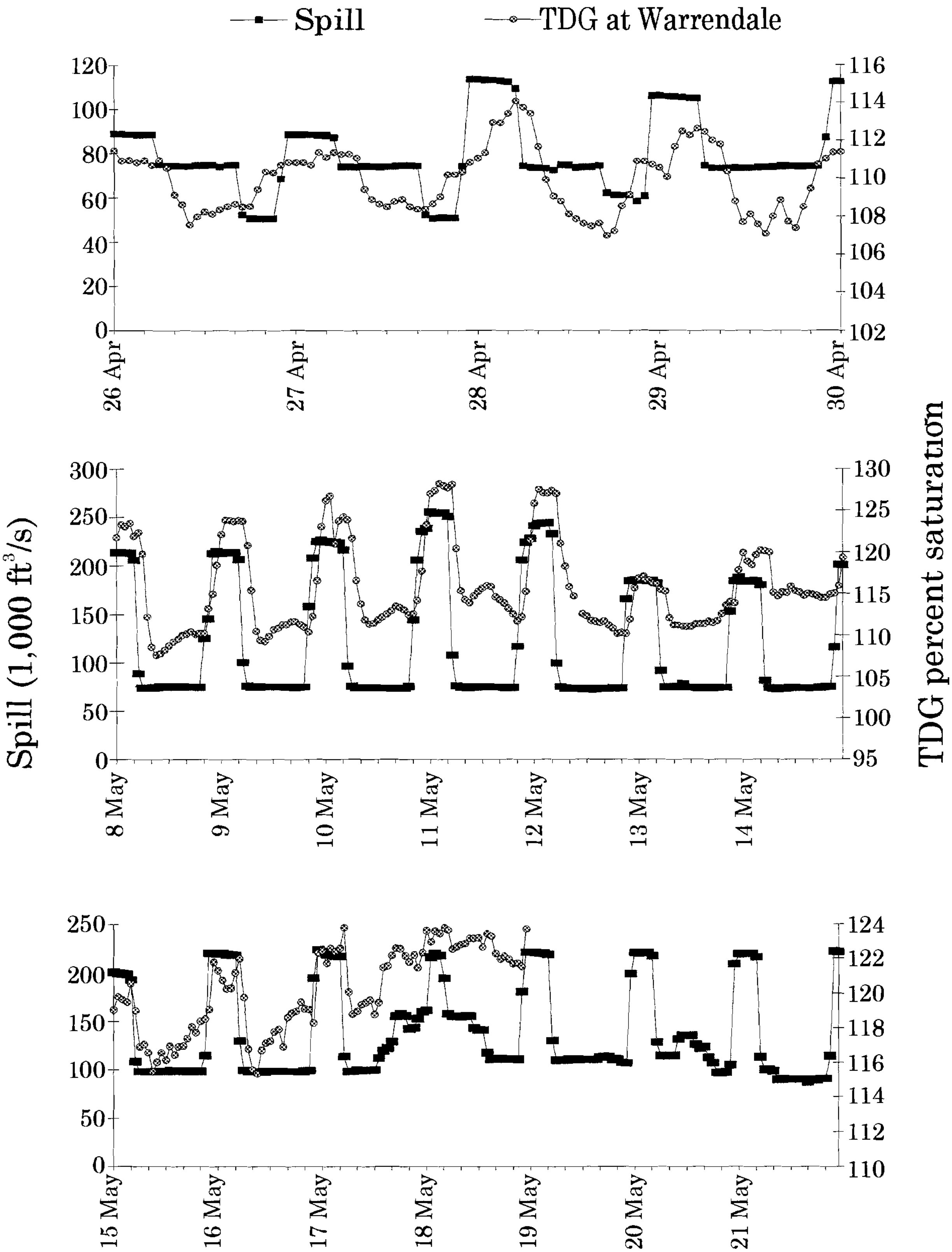
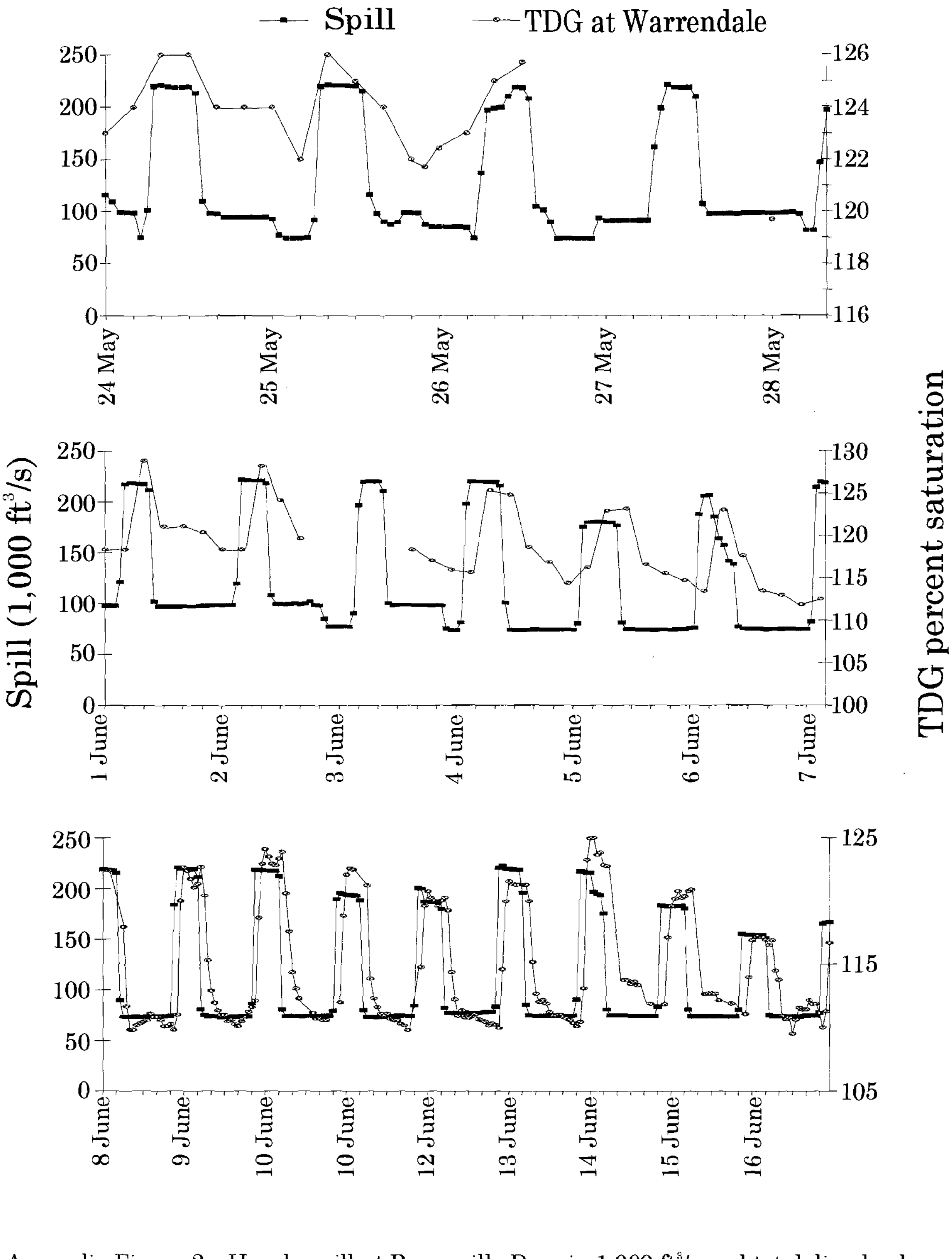
APPENDIX



Appendix Figure 1. Hourly spill at Bonneville Dam in 1,000 ft^3/s and total dissolved gas (TDG) saturation values at Warrendale, Oregon, Columbia River, 1993. By convention, English units were used for river flow volumes (1,000 ft^3/s = 28.3 m^3/s).



Appendix Figure 2. Hourly spill at Bonneville Dam in 1,000 ft^3/s and total dissolved gas (TDG) saturation values at Warrendale, Oregon, Columbia River, 1993. By convention, English units were used for river flow volumes (1,000 ft^3/s = 28.3 m^3/s).

Appendix Table 1.--Summary of samples taken when observations of gas bubble disease (GBD) were made in fish and invertebrates sampled downstream from Bonneville Dam, 1993.

Date	Time	Location	RKm	Saturation (%)	Species	No.	No. with signs of GBD	Location of signs of GBD
19 May	0830	Rooster Rock	208	121	Chinook salmon	13	0	
19 May	0830	Rooster Rock	208	121	Coho salmon	26	2	caudal fin
19 May	0830	Rooster Rock	208	121	Largescale sucker	1	0	
19 May	0830	Rooster Rock	208	121	Peamouth	3	0	
19 May	0830	Rooster Rock	208	121	Steelhead	1	0	
21 May	0803	Rooster Rock	208	121	Chinook salmon	82	0	
21 May	0803	Rooster Rock	208	121	Coho salmon	17	13	
21 May	0803	Rooster Rock	208	121	Crayfish	1	0	
21 May	0803	Rooster Rock	208	121	Peamouth	3	0	
21 May	0803	Rooster Rock	208	121	Squawfish	2	0	
21 May	1300	Lemon Island	180	121	Chinook salmon	68	1	anal fin
21 May	1300	Lemon Island	180	121	Coho salmon	1	1	anal fin
21 May	1300	Lemon Island	180	121	Peamouth	1	0	
21 May	1300	Lemon Island	180	121	Squawfish	1	0	
22 May	1045	Puget Island	74	116	Asian clam	3	0	
22 May	1045	Puget Island	74	116	Chinook salmon	102	1	anal fin
22 May	1045	Puget Island	74	116	Coho salmon	1	1	anal fin
22 May	1045	Puget Island	74	116	Peamouth	35	1	anal fin
22 May	1045	Puget Island	74	116	Starry flounder	4	0	
22 May	1045	Puget Island	74	116	Stickleback	73	0	
25 May	0712	Rooster Rock	208	122	Chinook salmon	83	0	
25 May	0712	Rooster Rock	208	122	Coho salmon	4	2	anal fin
25 May	0712	Rooster Rock	208	122	Sockeye salmon	1	0	
25 May	0712	Rooster Rock	208	122	Steelhead	5	1	anal fin
1 Jun	1550	Beacon Rock	228	116	Chinook salmon	13	0	
1 Jun	1550	Beacon Rock	228	116	Crayfish	20	0	
1 Jun	1550	Beacon Rock	228	116	Sculpin	25	1	eye
1 Jun	1550	Beacon Rock	228	116	Stickleback	14	2	post. body
1 Jun	1550	Beacon Rock	228	116	Sucker	1	0	
2 Jun	1748	Hoagys Bar	91	107	Asian clam	20	0	
2 Jun	1748	Hoagys Bar	91	107	Chinook salmon	93	0	
2 Jun	1748	Hoagys Bar	91	107	Coho salmon	2	0	
2 Jun	1748	Hoagys Bar	91	107	Dragonfly larvae	7	0	
2 Jun	1748	Hoagys Bar	91	107	Largescale sucker	3	0	
2 Jun	1748	Hoagys Bar	91	107	Peamouth	17	0	
2 Jun	1748	Hoagys Bar	91	107	American shad	2	0	
2 Jun	1748	Hoagys Bar	91	107	Squawfish	2	0	
2 Jun	1748	Hoagys Bar	91	107	Starry flounder	20	0	
2 Jun	1748	Hoagys Bar	91	107	Stickleback	2	0	
3 Jun	1620	Beacon Rock	228	114	Chinook salmon	77	0	
3 Jun	1620	Beacon Rock	228	114	Crayfish	4	0	
3 Jun	1620	Beacon Rock	228	114	Prickly sculpin	61	0	
3 Jun	1620	Beacon Rock	228	114	Stickleback	11	0	
4 Jun	1147	Wallace Island	78	112	Crayfish	9	0	
4 Jun	1147	Wallace Island	78	112	Killifish	1	0	
4 Jun	1147	Wallace Island	78	112	Prickly sculpin	2	0	
4 Jun	1147	Wallace Island	78	112	Stickleback	26	0	
7 Jun	1159	LwrEndLordIsl	99	108	Chinook salmon	26	0	
7 Jun	1159	LwrEndLordIsl	99	108	Killifish	1	0	
7 Jun	1159	LwrEndLordIsl	99	108	Prickly sculpin	38	0	
7 Jun	1159	LwrEndLordIsl	99	108	Starry flounder	2	0	
7 Jun	1159	LwrEndLordIsl	99	108	Stickleback	18	0	
8 Jun	1248	Lewis&Clark1	96	116	Chinook salmon	4	0	
8 Jun	1248	Lewis&Clark1	96	116	Killifish	3	0	
8 Jun	1248	Lewis&Clark1	96	116	Peamouth	7	0	
8 Jun	1248	Lewis&Clark1	96	116	Prickly sculpin	10	0	
8 Jun	1248	Lewis&Clark1	96	116	Redside shiner	6	0	
8 Jun	1248	Lewis&Clark1	96	116	Stickleback	2	0	
9 Jun	1845	Hump Island	96	110	Chinook salmon	53	0	
9 Jun	1845	Hump Island	96	110	Coho salmon	7	2	anal/caudal fins
9 Jun	1845	Hump Island	96	110	Crayfish	2	0	
9 Jun	1845	Hump Island	96	110	Largescale sucker	24	0	
9 Jun	1845	Hump Island	96	110	Peamouth	5	0	
9 Jun	1845	Hump Island	96	110	Prickly sculpin	20	0	
9 Jun	1845	Hump Island	96	110	American shad	1	0	

Appendix Table 1. Continued.

Date	Time	Location	RKm	Saturation (%)	Species	No.	No. with signs of GBD	Location of signs of GBD
9 Jun	1845	Hump Island	96	110	Squawfish	3	0	
9 Jun	1845	Hump Island	96	110	Starry flounder	2	0	
9 Jun	1055	Puget Island	74	110	Chinook salmon	20	0	
9 Jun	1055	Puget Island	74	110	Coho salmon	2	0	
9 Jun	1055	Puget Island	74	110	Largescale sucker	3	0	
9 Jun	1055	Puget Island	74	110	American shad	1	0	
9 Jun	1055	Puget Island	74	110	Squawfish	1	0	
9 Jun	1055	Puget Island	74	110	Starry flounder	11	0	
9 Jun	1055	Puget Island	74	110	Stickleback	51	0	