Gas Bubble Disease in Resident Fish of the Lower Clark Fork River

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Abstract. – Gas bubble disease (GBD) occurs in resident fish of the lower Clark Fork River exposed to total dissolved gas (TDG) supersaturation produced by spill at upstream hydroelectric projects. This report describes the incidence and severity of GBD observed in fish routinely collected by electrofishing and other techniques during periods of high supersaturation from 1997 to 2000. These data include GBD observations for 1997, a year of extremely high runoff resulting in TDG levels approaching 150% of saturation, and 1999, a year of moderately high TDG levels (typically 120-130% of saturation). Although electrofishing only samples that portion of the fish populations present near the river surface (upper 2m) in a deep stream (3-25m) like the lower Clark Fork, the observed incidence and severity of GBD was substantially lower than anticipated for the levels of TDG measured. It appears that the majority of fish are spending sufficient time at depths that avoid or mediate both the incidence and severity of GBD when TDG supersaturation is in the range of 120-130% of saturation. Fish also have access to a number of tributaries that have little or no supersaturation, and to Lake Pend Oreille where fish commonly occupy depths providing hydrostatic compensation that eliminates exposure to supersaturation..

INTRODUCTION

Monitoring of resident fish for signs of gas bubble disease (GBD) in the lower Clark Fork River in northern Idaho was conducted during the spill seasons of 1997 through 2000 to determine the incidence and severity of GBD in the resident fish populations. Our multi-year investigation of GBD in resident fish in the lower Clark Fork River is an attempt to provide information leading to a better understanding of the biological implications of total dissolved gas (TDG) supersaturation when it occurs in a river situation with free swimming fish. Most previous investigations have either been laboratory studies or investigations of the effects of TDG on anadromous salmonids.

Extensive research during the 1960's and 1970's determined that TDG supersaturation can lead to fish mortalities in the Columbia River system (Ebel et al. 1975, Weitkamp and Katz 1980). Resulting changes in mainstem hydroelectric project operations reduced or eliminated supersaturation in most years. In the 1990's the use of spill as a juvenile fish passage measure together with high runoff conditions in some years resulted in renewed focus on supersaturation as a potential cause of fish mortalities. The visible signs of GBD and the potential effects on survival of exposed fish have been well documented by controlled exposure investigations primarily under laboratory conditions, but also in a few field efforts (Dawley and Ebel 1975, Nebeker and Brett 1976, Weitkamp 1976, Weitkamp and Katz 1980, Ryan et al. 2000). However, most of these investigations limit fish to shallow depths, thereby maximizing the effects of elevated TDG levels by preventing hydrostatic compensation. The hydrostatic pressure provided by depth, reduces the effective TDG level at a rate of about 10% of saturation per meter.

The physical evaluations involved measuring TDG levels that occurred in the lower Clark Fork River and Lake Pend Oreille during the spill season (typically April through June). Routine monitoring upstream and downstream from each of the lower Clark Fork hydroelectric projects (Noxon Rapids and Cabinet Gorge Dams) provided records of the TDG conditions experienced by resident fish downstream of Cabinet Gorge Dam.

Cabinet Gorge Dam is the downstream hydroelectric project on the lower Clark Fork River in northern Idaho (Figure 1). The owner/operator, Avista Corporation (formerly Washington Water Power), funded this investigation to support an FERC relicensing application. Data previously collected indicated there is a potential for elevated TDG levels in the river downstream from Cabinet Gorge Dam during periods of substantial spill. The hydraulic capacity of the Cabinet Gorge powerhouse (1,076 m^3/s, 38 kcfs) is often exceeded during late spring runoff periods resulting in substantial spill when river discharge reaches 1,700-3,540 m^3/s (60 to 125 kcfs).

The Clark Fork River discharges into Lake Pend Oreille in northern Idaho. Lake Pend Oreille an exceptionally large and deep lake of 34,804 hectares and depths up to 366 m that offers the opportunity for depth compensation to avoid the effects of TDG supersaturation. During high runoff and high TDG years the surface water of Lake Pend Oreille also becomes supersaturated to levels approaching those in the lower Clark Fork River.

METHODS

Investigation of gas bubble disease (GBD) in resident fish of the lower Clark Fork River involved primarily collecting fish from shallow water throughout the spring spill period when total dissolved gas (TDG) levels were likely to be high. These fish were examined for external signs of GBD. Collection of fish by boat electrofishing samples only that portion of the population in shallow water thereby biasing the sample to those members of the population most likely to experience GBD. However, it was the only practical capture technique available to collect large numbers of fish at multiple locations in a large swift river such as the lower Clark Fork River. Some fish were collected by trap and beach seine at the mouth of the river where it enters Lake Pend Oreille. These capture techniques also tend to collect those fish occupying shoreline and near surface portions of the river. The trap and seine techniques produced samples too small and with too few species to provide an adequate sampling technique for this investigation.

Additionally, several resident species were also studied by holding juveniles in live cages during periods of high TDG supersaturation.

RESIDENT FISH COLLECTION

Resident fish were collected from shallow water in the lower Clark Fork River primarily by electrofishing. In 1998 and 1999 fish were also collected near the mouth of the Clark Fork using an Oneida trap and by beach seining to potentially collect species or life stages not included in the electrofishing samples. Electrofishing was conducted adjacent to the riverbanks, at locations where water were velocities sufficiently low to provide a reasonable probability of capturing fish by shocking.

Electrofishing occurred at night from a small jet boat equipped with a Coffelt VVP-2E electroshocker. Electrofishing transects established at the beginning of the study were surveyed weekly from mid-May through late June. Transects were selected at locations that provided relatively low river velocities. These were all side channels or river edge locations protected from the main river current. They also tended to have relatively shallow depths of less than four meters. The collection permit issued for this investigation prohibited collection by electrofishing in the river delta area due to the potential presence of bull trout. A single electrofishing pass was made along each transect during each sampling event with sampling duration timed to provide catch per unit effort estimates. Individual transects were not sampled on successive nights and not all transects were sampled each week. In addition to the routine GBD sampling effort, additional electrofishing was conducted at times to provide fish for the coordinated radio-tagging program.

Electrofishing began each night at sundown with a crew of three people consisting of two netters and a boat operator. Stunned fish were dip netted into a live-tank for examination at completion of the transect. Information recorded for each fish included: species, fork length, presence of any abnormalities, externally observable signs of GBD, and presence of tags or previous marks. Fish greater than approximately 100 mm were marked with a hole punch in the caudal fin to indicate they had been previously examined if they were recaptured. Smaller fish were not marked, due to the relatively large portion of the caudal fin that would be lost by hole punching. Trout, with the exception of brown trout, were scanned for a PIT (Passive Integrated Transponder) tag and the number recorded when tags were detected. Untagged trout were tagged with a PIT tag to assess recapture frequencies of trout species, as well as monitor long-term movement through potential recapture events in subsequent years by other sampling efforts. Following examination and marking, the fish were released near their capture location

GAS BUBBLE DISEASE EXAMINATIONS

Our investigation used external signs of GBD as a practical means of determining the incidence and severity of the disease in a wild population. Fish could be examined relatively quickly in the field without damage to the individuals. Mesa et al. (2000) determined bubbles in the fins are a useful indicator of the severity of GBD, as they progressively increase over time with acute exposures to supersaturation (120-130% saturation).

Each collected fish was examined by a trained biologist for external signs of GBD using the U.S. Geological Survey Columbia River Research Laboratory protocols for juvenile salmonids (USGS 1997). The eyes and unpaired fins were examined for signs of GBD and rated for severity based on the presence or absence of bubbles, with each fish rated according to the following scale:

0 = no observable bubbles
1 = 1-5% of a fin covered with bubbles
2 = 6-25% of a fin covered with bubbles
3 = 26-50% of a fin covered with bubbles
4 = greater than 50% of a fin covered with bubbles.

Ranks 1 and 2 appear to be evidence of GBD of minor severity, with these fish typically not showing any other visible evidence of ill health. Although rank 3 and 4 are evidence of more severe GBD, these fish also commonly show no visible signs of ill health other than the bubbles. Fish were also examined for exophthalmia (protrusion of the eyeball from the orbit), hemorrhaging, and fungal infections, that can indicate severe or previous GBD (Weitkamp 1976, 1980). One of the major challenges in assessing the biological effects of TDG supersaturation is relating the detectable signs of GBD to impaired survival or mortality. As shown by Weitkamp (1976), fish with severe signs of GBD can recover, and some fish not showing signs of GBD appear to succumb to high levels of TDG supersaturation without showing obvious signs of GBD.

LIVE CAGE OBSERVATIONS

In 1997 juvenile rainbow and cutthroat trout from the Clark Fork Hatchery were held in shallow live cages at two locations on the lower Clark Fork River. Live cages were approximately 2 m deep by 1.5 m wide and 2 m long, enclosed at the top to prevent avian or mammalian predation. Approximately 100-125 rainbow and cutthroat trout were placed in each live cage for each test. Test fish were held a maximum of two weeks. Trout were fed every other day during the initial test and then every day during subsequent tests. Twenty-five fish were examined for external GBD signs every other day during the initial test and every day during subsequent tests.

In 1999 juvenile kokanee were held in deep live cages placed within a Lake Pend Orielle marina about 7 km from the mouth of the Clark Fork River. A second live cage was placed at the south end of Lake Pend Orielle (about 32 km from the river mouth), but strong currents caused the deep cage to collapse on itself. Live cages were 2 m in diameter by 9 m deep, allowing the young kokanee the opportunity to migrate over a substantial range of depths as they appear to do in Lake Pend Oreille.

RESULTS

Electrofishing in the lower Clark Fork River was a successful technique for collecting substantial numbers of those species known to reside in the river despite the limited capacity of the technique to collect fish deeper than about 2 m below the surface. Fourteen species were collected, with a few species representing the majority of the fish collected. Largescale sucker (*Catostomus macrocheilus),* northern pikeminnow (*Ptychocheilus oregonensis*), peamouth chub (*Mylocheilus caurinus*), and mountain whitefish (*Prosopium williamsoni*) (Table 1) were the most abundant species. These four species contributed 67% to 84% of the collected fish each year. Salmonids collected (2-13% of catch/year) included brown trout (*Salmo trutta*), westslope cutthroat trout (*Oncorhynchus clarki*), rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*), and kokanee (*O. nerka*). Other species sampled included redside shiner (*Richardsonius balteatus*), longnose sucker (*Catosomus catostomus*), yellow bullhead (*Ictalurus natalis*), and yellow perch (*Perca flavescens*).

Table 1. Numbers of each species collected by electrofishing and percentage of fish showing any signs of GBD, lower Clark Fork River.

SPECIES	1997		1998		1999		2000	
	#	%	#.	%	#.	%	#.	%
rainbow trout	0	0	9	0	34	4.0	41	0
kokanee	0	0	44	0	64	3.1	15	0
brown trout	2	50.0	8	12.5	25	4.0	23	0
cutthroat trout	0	0	21	0	34	0	21	0
bull trout	0	0	0	0	8	0	3	0
lake trout	0	0	0	0	1	0	0	0
longnose sucker	2	0	30	0	64	4.7	20	0
largescale sucker	7	71.5	441	0	1,249	11.4	244	0.4
mountain whitefish	1	0	51	0	417	0.2	93	0
northern pikeminnow	33	0	333	0	303	0.3	165	0
peamouth chub	31	0	408	0	426	1.2	148	0
yellow bullhead	0	0	0	0	21	14.3	1	0
tench	0	0	0	0	1	0	0	0
redside shiner	23	0	52	0	60	0	3	0
yellow perch	3	0	5	0	0	0	1	0
smallmouth bass	0	0	0	0	2	0	0	0
Total	107	5.6%	1,409	0.1%	2,811	5.9%	778	0.1%

Fish were also collected by beach seine and Oneida trap from the river delta area in 1998 and 1999. Although the catch composition was similar to the electrofishing catch in 1999, the catch was substantially different in 1998 (Table 2). In 1999, 5.4% of the beach seine and Oneida trap catch were salmonids, compared to 5.9% in the electrofishing catch. However in 1998, no salmonids were caught by seine or trap while they made up 5.8% of the electrofishing catch.

Table 2. Numbers of each species collected by Oneida trap and beach seine and percentage of fish showing any signs of GBD, lower Clark Fork River.

SPECIES	1998		1999	
	#.	%	#.	%
kokanee	0	0	0	0
brown trout	0	0	1	0
longnose sucker	0	0	20	0

largescale sucker	2	0	6	0
mountain whitefish	0	0	15	0
northern pikeminnow	121	0	169	1.2
peamouth chub	36	0	74	5.4
yellow bullhead	34	0	462	1.1
tench	27	0	38	0
redside shiner	49	0	33	0
yellow perch	0	0	31	0
flathead minnow	0	0	103	1.9
Total	269	0%	952	1.4%

INCIDENCE OF GAS BUBBLE DISEASE

During the first year of the investigation (1997) only a small number of fish were collected, as this was an attempt to explore various techniques for collection and observation of fish. The boat electrofishing equipment was not available until late in the spill season. However, the extremely high levels of TDG (132-158% of saturation) for several months resulted in an apparently high incidence of GBD signs in largescale suckers and brown trout (Table 1), although these are based on small sample sizes. Surprisingly signs of GBD were not observed in northern pikeminnow, peamouth chub or redside shiner although substantial numbers of these species were collected.

Signs of GBD were observed only in one brown trout of the 1,409 fish collected by electrofishing in 1998. This extremely low incidence of GBD was also lower than anticipated with the moderately high levels of TDG recorded in 1998. TDG typically reached 120% of saturation daily during this period.

In contrast, 10 of the 15 species collected by electrofishing in 1999 showed signs of GBD, with 5.9% of the fish collected showing signs. The highest incidence occurred in yellow bullhead and largescale sucker (14.3% and 11.4%, respectively), although only 21 yellow bullhead were examined in 1999. The incidence of GBD in fish collected by beach seine and Oneida trap was substantially lower (1.4%) than for fish captured by electrofishing (5.9%). The species showing the highest incidence (5.4%) was peamouth chub, with all other species showing less than 2.0% incidence. These higher rates of GBD, compared to 1998, correspond to the generally higher TDG levels (typically between 120% and 130% of saturation). A much smaller portion of the fish collected by Oneida trap exhibited signs of GBD (<2%). Bubbles were observed in the fins of northern pikeminnow (1.2%), peamouth chub (5.4%), and yellow bullhead (1.1%).

Signs of GBD were essentially absent from the 778 resident fish examined in 2000. Signs of GBD were observed in only one fish during the season. This fish was a longnose sucker captured 11.7 km downstream from Cabinet Gorge Dam at the Mosquito Creek transect area on May 31. The sucker exhibited only minor signs of GBD (Rank 1 in the caudal fin). The highest instantaneous and hourly average TDG levels of the season (132% and 131% of saturation, respectively) occurred during the week prior to capture of this sucker. The hourly averages during that week ranged from 103% to 131% of saturation, while the daily averages ranged from 104% to 115% of saturation.

In addition to the 778 resident fish examined in 2000, 28 trout were also captured on May 8 and 10, for the radio tagging program. These fish were not examined for signs of GBD to avoid the need to anesthetize them multiple times and to minimize the overall handling stress prior to tagging. No signs of GBD were observed in these fish the following day when they were examined during the tagging process. Prior to being examined these fish were held for at least eight hours in a well water supply with TDG levels near saturation.

TOTAL DISSOLVED GAS LEVELS

Total dissolved gas levels varied greatly among years and within years (Figure 2). In 1997 TDG levels were exceptionally high resulting from a near record runoff year. The high river flows resulted in continuous spill at all dams on the Clark Fork River for a prolonged period of several months. In the lower Clark Fork River TDG levels remained between 143% and 158% of saturation for over a month, with another month of levels greater than 127% of saturation.

Figure 2 shows the patterns of TDG that occurred during the four years of this investigation. In 1997 exceptionally high levels of TDG persisted for several months. During 1998 and 2000 TDG levels spiked daily to levels near or slightly higher than 120% of saturation. In 1999 TDG levels remained between 120 and 130% of saturation for over a month.

Gaps in the monitoring records occurred in several years due to equipment failures and loss of a data file in one year. However, we were able to determine the general pattern of TDG levels for these periods using forebay TDG records together with records of spill at Cabinet Gorge Dam. General levels of TDG for periods of interest are provided in Table 3.

Table 3. Total dissolved gas levels (mean and range) during periods fish were examined for signs of GBD in the lower Clark Fork River.

YEAR	May 15-31	June 1-15	June 16-30	July 1-15
1997	150 (142 – 158)	146 (143 – 151)	142 (132 - 145)	133 (127 – 139)
1998	103 (100 - 119)	112 (104 – 121)	117 (103 - 131)	113 (103 - 121)
1999	114 (102 – 128)	125 (119 – 137)	125 (123 - 129)	107 (105 – 117)
2000	108	104	107	na

	(103 - 132)	(101 – 123)	(102 - 128)

In 1998 the TDG levels were moderate with frequent occurrence of readings at or above 120% of saturation interspersed with periods below 110% of saturation. River discharge frequently required spill for only a portion of each day producing alternating periods of low and moderately high TDG supersaturation. Only during a six day period in late June did TDG levels remain continuously above or near 120% of saturation. Mean TDG levels remained between 110 and 120% of saturation throughout June and early July.

In 1999 runoff was again high due to late spring rains, resulting in continuous spill at Cabinet Gorge Dam during late May and most of June. This spill resulted in TDG levels consistently between 120% and 130% of saturation for approximately one month. No periods of low TDG levels were recorded in the lower Clark Fork River during this period.

Moderate runoff occurred in 2000 resulting in intermittent spill at Cabinet Gorge Dam. Intermittent spill produced only intermittently high TDG levels in the lower Clark Fork River throughout the 2000 spill season. Recorded levels of TDG commonly reached 115-130% of saturation each day for a few hours followed by a period of about 105% of saturation. However, mean daily TDG levels remained below 110% of saturation.

LIVE CAGE OBSERVATIONS

In 1997 when TDG levels were exceptionally high (140-150%), all young rainbow and cutthroat trout died that we held in cages with a maximum depth of two meters. In the first test, when fish were exposed to TDG levels greater than 140% of saturation, all fish died within four days. Most fish surviving more than one or two days exhibited severe signs of GBD with bubbles in paired fins, lateral lines, and other body areas. In a second test with TDG levels between 123% and 138% of saturation relatively small numbers of fish died (< 20% during the 15 day test), and few showed any signs of GBD. Samples of 25 fish were examined each day during the second test with 0-28% showing signs of GBD.

In 1999 young kokanee held in deep (9 m) live cages in Lake Pend Oreille experienced no detectable mortality. The kokanee were exposed to TDG levels of about 125% of saturation during the two week tests. We were unable to detect any signs of GBD in the kokanee, which were examined ever other day.

DISCUSSION

Our observations indicate the depth distribution of resident fish in the lower Clark Fork River limits the development of gas bubble disease (GBD) when total dissolved gas (TDG) supersaturation exceeds 110% of saturation. We found fish collected from shallow portions of the river showed a low incidence and a low severity of GBD, while fish held in shallow water suffered high mortalities due to GBD. Our observations indicate there is a major difference in the depth distribution of fish in the river as compared to fish in laboratory and live cage investigations. These observations suggest caution should be used in employing the results of the laboratory and live cage investigations to interpret conditions in the natural environment. Unlike most water quality issues, the depth distribution of the fish in their natural habitat greatly influences the biological effects of TDG supersaturation.

The electrofishing sampling technique used to collect most of our samples selects the portion of the fish population present in shallow water. The technique used does not have the capacity to effectively collect fish deeper than about 2 m (6 ft) below the surface. Because the levels of supersaturation have a greater biological effect in shallow water (surface to 1-2 m) than at greater depths, this investigation is likely to overestimate the incidence of GBD in the river's total population.

GBD INCIDENCE AND SEVERITY

The incidence and severity of GBD was highly variable among the four years investigated. However, both the incidence and severity of GBD signs were substantially lower than predicted based on laboratory and live cage results. We found a surprisingly low incidence of GBD in most species collected in 1997 given the extremely high levels of TDG (140-150% of saturation) that occurred continuously over several months. It appears that the extremely high water levels provided by the high flow may have resulted in most fish occupying sufficient depths to avoid the effects of the high levels of TDG supersaturation. Although we found a high incidence of GBD in brown trout and largescale sucker, the numbers collected were too small to support strong conclusions. Unfortunately our sample size (107 fish) was relatively small during this initial year of the investigation.

During subsequent years the lower Clark Fork River had lower levels of TDG supersaturation. In 1998 TDG levels commonly exceeded 120% of saturation, but only for intermittent periods of less than a day throughout most of the spill period.

During 1998 we collected a large sample (1,409 fish) but found only a single fish with signs of GBD. This brown trout had minor signs of a single bubble in the anal fin. These data provide an indication that intermittent exposure of 120-125% TDG saturation has essentially no effect on the resident fish of the lower Clark Fork River. The TDG levels in 1999 were somewhat higher (120-130%) and remained continuously high for approximately one month. During these conditions we observed relatively high incidences of GBD in a number of species. Largescale suckers and yellow bullheads respectively had incidences of 11.4% and 14.3% GBD. Rainbow trout, kokanee fry, brown trout, and longnose sucker each had incidences of GBD in the range of 3-5% during the period of continuous exposure to 120-130% of saturation. Approximately 10% of the fish were collected late in the spill season when TDG levels were generally less than 120% of saturation.

Although most of the fish collected in 1999 that showed signs of GBD had only minor signs (Rank 1 or 2 in one or two fins), a few had slightly more severe signs (Rank 3 or 4) in the dorsal fin. Only a single fish had exophthalmia. None showed any other obvious signs of debilitating effects. Signs of GBD generally began to appear in the fish after 10 days or more of continuous exposure to TDG of about 125% saturation. Bubbles were most commonly detected in the dorsal and caudal fins, occasionally in the anal fin, and rarely in the paired fins. Bubbles in fins are overt signs of chronic GBD that Mesa and Warren (1997) found does not increase the susceptibility of young salmon to predation by northern pikeminnow. They determined exposure to 130% TDG in water not exceeding 0.3 m deep produced acute GBD with an increased risk of predation.

Mesa et al. (2000) and previously Jensen et al. (1986) characterized chronic and acute GBD. Mesa et al. found exposure to 120-130% TDG in water less than 0.3 m produced acute GBD, while exposure to 110 % in shallow water produced chronic GBD. At 130% TDG Mesa et al. determined the severity of bubbles in fins is highly correlated with mortality. The low severity of bubbles in fins we observed is an indication mortality was either minor on none existent. It is unlikely the fish we examined had substantially more severe bubbles that had disappeared. Elston et al. (1997), Hans et al. (1999) and Mesa et al. (2000) have each determined that bubbles in fins are a relatively persistent sign of GBD.

The 1999 data provide an indication that the biological effect of TDG in the 125-130% range is prevalent only following a prolonged period of exposure. As shown in Figure 3 we observed signs of GBD in a small percentage of fish (0-3%) during the first two weeks of elevated TDG. After about two weeks of continuous TDG in the range of 125-130% we began to see substantial numbers of fish collected from the shallow water areas showing signs of GBD.

During the period of elevated TDG in1999, the percentage of fish showing signs of GBD was much higher in those fish collected from shallow habitat areas than those collected from the shorelines of deep water areas (Figure 3). Other than a single date (6/22) the percentage of fish from deep water areas that showed signs of GBD did not exceed 3%, while the percentage of fish collected from shallow areas exceeded 25% on one occasion.

The intermittent exposure to relatively high TDG (120-130%) observed in 1998 and 2000 appears to pose little risk of GBD to fish in the lower Clark Fork River. Our data suggest that TDG levels below 125% of saturation do not result in a substantial incidence of GBD in fish residing in the lower Clark Fork River. The intermittent exposure together with the depth distribution of the fish (Weitkamp et al. in press) apparently prevented nearly all fish from developing any signs of GBD in most years. It is not likely the fish lost signs of GBD in the brief periods (<24 hr) between intermittent exposures and collection. Hans et al. (1999) reported the prevalence of bubbles on external surfaces of chinook and steelhead decreased slowly from about 95% at the end of exposure to high TDG levels to about 40% at the end of four days.

Even with the continuous exposure to 120-130% TDG for more than a month in 1999, the effect on the fish population appears to have been slight. The signs of GBD observed in a small portion of the fish population appeared to not have a debilitating effect on these fish. As our samples are only from shallow water they most likely overestimated the incidence and severity of GBD in the fish population of the lower Clark Fork River. Since we were effective in collecting only that portion of the population present near the river's surface (0-2 m), we collected those fish most likely to be exposed to TDG supersaturation.

Our observations indicate the development of external signs of GBD is related to both the exposure level and exposure duration. Therefore, the more time that the fish are exposed to levels below the threshold for bubble formation the longer it would take for signs of GBD to appear. In addition, Weitkamp and Katz (1980) indicated that repeated exposures might increase the tolerance to supersaturated water.

If GBD were prevalent in the lower Clark Fork River fish population during the periods of high TDG we should have seen numerous fish with bubbles in their fins. Although fish do not develop signs of GBD with many days exposure to 110% of saturation when they are restrained in water less than 30 cm deep, they do develop GBD rapidly as TDG levels increase to 120% and higher with the fish restrained to shallow water (Mesa et al. 2000).   During the extensive periods of time conducting various monitoring efforts on the river we did not observe any dead or moribund fish in the river during the four years of our investigation.

DEPTH EFFECTS

Depth is a critical consideration in evaluating potential effects of gas supersaturation on fish. Solubility of gas in water increases with depth resulting in a decrease in the percent saturation with increasing depth. As a result, total gas pressure measured at the surface is reduced approximately 10% for each one-meter increase in depth (Weitkamp and Katz 1980). As shown in Figure 2, fish two meters deep do not experience actual supersaturation when TDG is at 120% of saturation with reference to surface pressure. Consequently, as a fish increases its depth in water, the potential for GBD decreases. Therefore, surface-oriented fish will be most prone to GBD, while bottom-oriented fish are unlikely to be affected by supersaturation, unless they occupy very shallow water habitats for substantial periods. Fish moving over a range of depths will tend to recover from the signs of GBD during those periods when they are at depths providing compensation for the encountered TDG level, or may avoid developing signs of GBD by frequent excursions between shallow and deep water.

High water velocities together with substantial depths in the lower Clark Fork River prevent fish from holding near the water surface except in areas close to the shorelines. Velocities less than 0.3 m/s occur only at the river's mouth, near main channel shorelines, along the channel bottom, and in the several side channels. The depths of the habitat available to most fish in these low velocity areas appears to provide substantial hydrostatic compensation for the levels of TDG supersaturation that commonly occur in the river.

Depth potentially effects fish both by preventing exposure to supersaturation and by relieving the effects of prior exposure. Moving from near surface water to greater depths provides for reabsorption of bubbles formed during the supersaturation exposure in shallow water. Elston et al. (1997) found fish with GBD lost bubbles in fins, lateral lines, and gills when exposed to pressure of 30.5 m depth for five minutes. Knittle et al. (1980) found that time spent at depth (prior to exposure to high TDG levels) appears to provide additional protection from GBD. They found that survival nearly doubled when juvenile steelhead were held for three hours at a depth of three meters, before being exposed to TDG levels of 130% of saturation. In the lower Clark Fork River we detected about 65% of radio-tagged fish at depths of at least three meters during the 2000 season (Parametrix 2000b). This behavior most likely contributed to the near absence of external GBD signs in fish collected during 2000. Fish sounding to depths of several meters are encountering only intermittent exposure to TDG during those periods when they are near the surface.

Our 1999 data provide an indication the availability of depth is a substantial factor in determining the incidence of GBD. We collected fish from five areas during 1999. Four of the areas have shallow water within a short distance of the main river channel there fish have access to substantial depths (3-5 m). We collected 2,095 fish from these areas with the incidence of GBD averaging 1.4%. In the shallow (<2 m) and isolated side channel we collected 1,396 fish with a 9.2% incidence of GBD.

MORTALITY

We were not able to detect evidence of any mortality in the resident fish populations at any time during our investigation. Although some of the collected fish showed signs of GBD in 1997 and 1999, none of these fish appeared to be suffering a debilitating effect. Emboli in the fins showed no signs of additional tissue damage or secondary fungal infections. A few fish showed opaque areas in caudal and dorsal fins that may have been the result of reabsorbed emboli.

It was obvious that holding cutthroat and rainbow trout in a live cage at depths of less than two meters during the exceptionally high TDG levels of 1997 (>140% of saturation) killed fish. All test fish held under these conditions died within four days. Many of these fish showed obvious severe signs of GBD prior to or at death. Observations on the river did not detect any dead fish during this and later periods, and signs of GBD were observed in only two of the eight species collected. We saw no evidence the resident population suffered effects similar to those observed in the live cage where fish were restrained within 2 m of the water surface. Unfortunately, our sample size of resident fish was sufficiently small (107 fish) that we are not able to reliably determine the effect of the extremely high TDG on the resident population.

During the second live cage test in 1997 when TDG levels dropped to less than 135% of saturation, the mortalities decreased to less than 20% of the test fish over the 15 day test period. Daily examination showed only a small portion of the live fish had signs of GBD (0-28%), usually only a few bubbles in one fin. The incidence of GBD in examined fish did not increase during the two-week test after the first several days. The difference in the mortality rates and incidence of GBD between these two live cage tests implies that in the second test many of the test fish were finding adequate hydrostatic compensation for the 135% of saturation within the 2 m depth of the live cage

The 1999 live cage test of young kokanee in a 9 m deep cage showed these fish did not develop signs of GBD when TDG levels were approximately 125% of saturation. The absence of GBD in the young kokanee was most likely due to their relatively deep distribution in the water column as has been observed by hydroacoustic investigations in Lake Pend Oreille.

The results of these four years of investigation indicate the moderate levels of TDG in the range of 120-130% of saturation are not having a substantial effect on the fish population of the lower Clark Fork River. Although signs of GBD do occur in small numbers of fish, we found no evidence of mortalities or of effects lasting beyond the period of supersaturation.

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REFERENCES

Dawley, E.M. and W.J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin 73:787-796.

Ebel, W.J., H.L. Raymond, G.E. Monan, W.E. Farr, and G.K. Tanonaka. 1975. Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia rivers. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington.

Elston, R., W. Colt, S. Abernethy, and W. Maslen. 1997. Gas bubble reabsorption in chinook salmon: pressurization effects. Journal of Aquatic Animal Health 9:317-321.

Hans, R.M., M. G. Mesa, and A.G. Maule. 1999. Rate of disappearance of gas bubble trauma signs in juvenile salmonids. Journal of Aquatic Animal Health 11:383-390.

Hill, J. and G.D. Grossman. 1993. An energetic model of microhabitat use for rainbow trout and rosyside dace. Ecology 74:685-698.

Knittle, M.D., G.A. Chapman, and R.R. Garton. 1980. Effects of hydrostatic pressure on steelhead survival in air-saturated water. Transactions of the American Fisheries Society 109:755-759.

Mesa, M.G., L.K. Weiland, and A.G. Maule. 2000. Progression and severity of gas bubble trauma in juvenile salmonids. Transactions of the American Fisheries Society 129:174-185.

Mesa, M.G., and J. Warren. 1997. Predator avoidance ability of juvenile chinook salmon (*Oncorhynchus tshawytscha*) subjected to sublethal exposures of gas-supersaturated water on survival. Canadian Journal of Fisheries and Aquatic Sciences 54:757-764.

Nebeker, A.V., and J.R. Brett. 1976. Effects of air-supersaturated water on survival of Pacific salmon and steelhead smolts. Transactions of the American Fisheries Society 105:338-342.

Parametrix, Inc. 2000a. Total dissolved gas monitoring Cabinet Gorge and Noxon Rapids hydroelectric projects, 2000. Report prepared for Avista Corporation, Spokane, Washington.

Parametrix, Inc. 2000b. Total dissolved gas monitoring Cabinet Gorge and Noxon Rapids hydroelectric projects, 1999. Report prepared for Avista Corporation, Spokane, Washington.

Parametrix, Inc. 2000d. Gas bubble disease lower Clark Fork River, 1999. Report prepared for Avista Corporation, Spokane, Washington.

Ryan, A.B., E.M. Dawley, and R.A. Nelson. 2000. Modeling the effects of supersaturated dissolved gas on resident aquatic biota in the main-stem Snake and Columbia Rivers. North American Journal of Fisheries Management 20:192-204.

USGS (U.S. Geological Survey). 1997. Protocol for determining gas bubble trauma in juvenile salmonids. Columbia River Research Laboratory, Cook, Washington.

Weitkamp, D. E. 1976. Dissolved gas supersaturation: live-cage bioassays at Rock Island Dam, Washington. Pages 24-36 *in* Fickeisen, D.H., and M.J. Schneider, editors. Gas bubble disease. Technical Information Center, Offices of Public Affairs, Energy Research and Development Administration.

Weitkamp, D. E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

LIST OF FIGURES

Figure 1. Lower Clark Fork River study area from Cabinet Gorge Dam to Lake Pend Orielle.

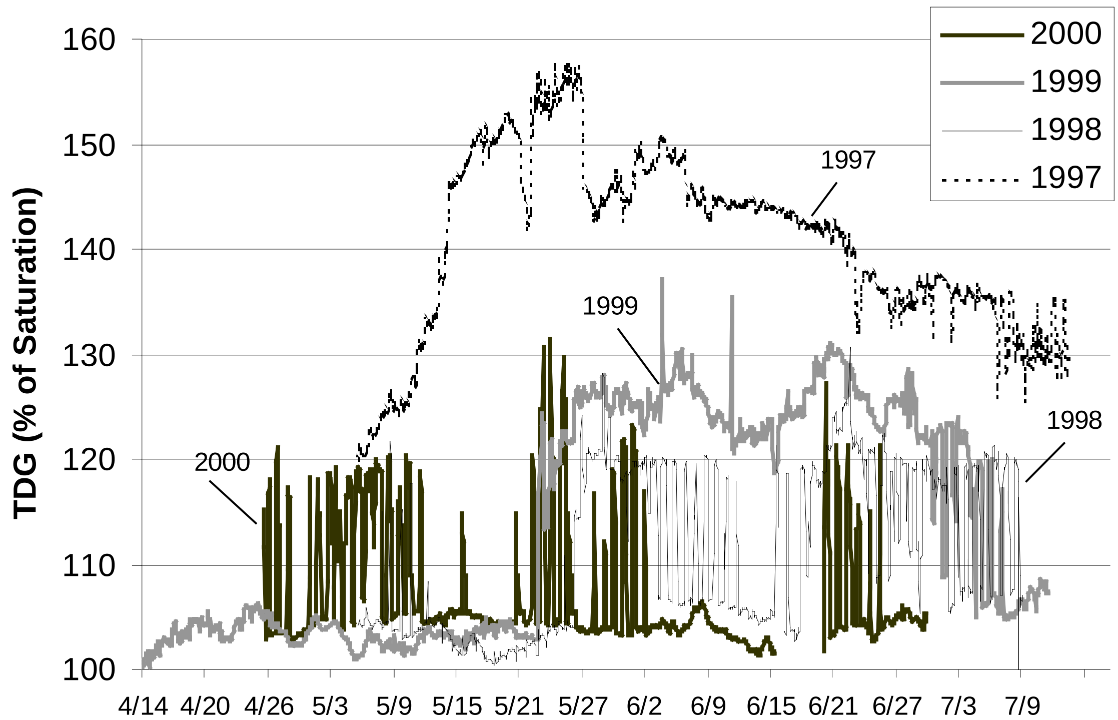

Figure 2. Total dissolved gas levels recorded downstream from Cabinet Gorge Dam during spring spill periods of 1997-2000.

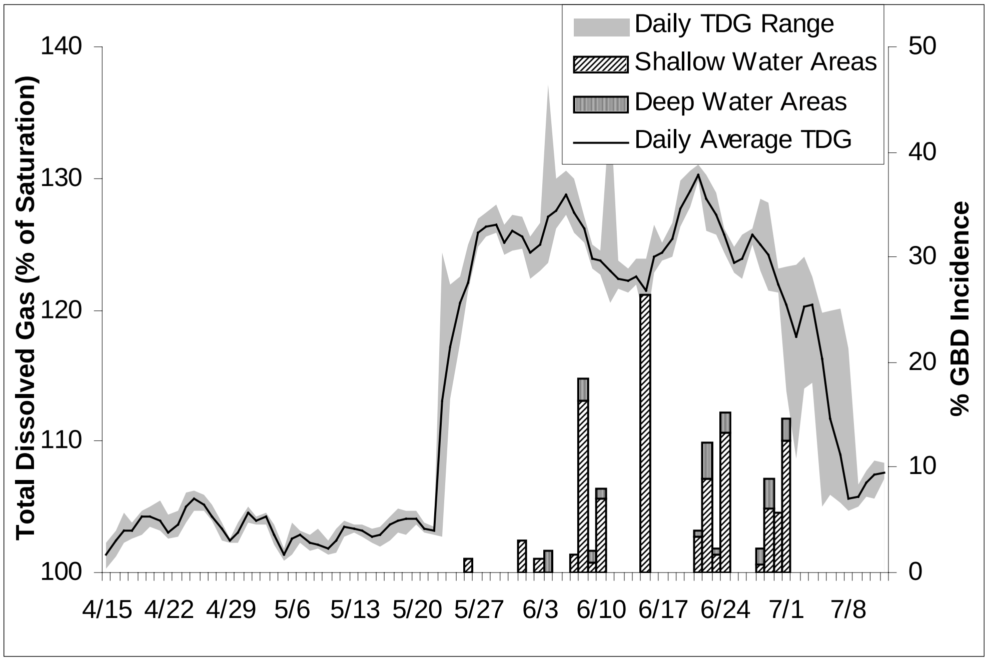

Figure 3. Total dissolved gas levels and incidence of GBD in fish collected during the 1999 spring spill period, lower Clark Fork River.