Behavior of Resident Fish Relative to TDG Supersaturation in the Lower Clark Fork River

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Abstract. – Behavior of resident fish exposed to total dissolved gas (TDG) supersaturation in Pacific Northwest rivers greatly influences the degree of supersaturation these fish actually experience. Because TDG supersaturation is a physical condition that is moderated by hydrostatic pressure, the depths occupied by fish during supersaturation conditions determine the biological effects experienced by members of the exposed population. Equipping fish with depth sensing radio tags documented that many of the fish spend sufficient time at depths of several meters or greater where they are not exposed to TDG supersaturation. These depths also provide an opportunity to recover from short-term exposure to supersaturation experienced by the fish during the periods they occupy shallower depths. Most species tagged had median and average depth distributions of about two meters or greater providing compensation for TDG supersaturation in the range of 120% of saturation or greater. Tagged rainbow trout generally remained in the river for only brief periods before returning to Lake Pend Oreille or tributaries to the lower Clark Fork River, where they were no longer exposed to TDG supersaturation.

INTRODUCTION

The depth distribution of fish greatly influences the biological effects of total dissolved gas (TDG) supersaturation. TDG is commonly measured and reported with reference to the water surface rather than with reference to the actual depth at which the measurement or sample is taken. TDG supersaturation, unlike other water quality parameters is a physical condition that is modified by hydrostatic pressure. Supersaturation at levels that cause bubbles to form in fish occupying shallow water is actually below supersaturation at some deeper level in the water column. The compensation provided by the hydrostatic pressure of water depth is equivalent to about 10% of saturation per meter of depth. Thus, TDG measurements of 120% of saturation relative to water surface pressure are only 110% of saturation at a depth of one meter, and 100% of saturation at two meters (Figure 1). Therefore fish remaining at depths of two meters or greater will not experience supersaturation when TDG levels are at or below 120% of saturation as measured with reference to the water surface.

This investigation is an attempt to determine the behavior of resident fish in the lower Clark Fork River of northern Idaho (Figure 2) to determine how the fishes' behavior influences their susceptibility to TDG supersaturation. The lower Clark Fork River commonly experiences TDG supersaturation resulting from spill at Cabinet Gorge Dam. Cabinet Gorge Dam is located within a tightly constrained physical setting that resulted in a limited powerhouse capacity (1,020 m^3/sec, 36,000 cfs). This hydraulic capacity is commonly exceeded resulting in spill for prolonged periods of days to weeks during the high runoff period of late spring and early summer of most years. Since the physical constraints of the locations make physical remedies to the supersaturation extremely difficult, it is desirable to understand how the supersaturation conditions are actually affecting the resident fish populations.

The investigation was conducted during the spring and early summer spill periods of 1998 to 2000. Resident fish were collected for the investigation as part of a complimentary investigation to determine the observable effects of supersaturation in resident fish in the lower Clark Fork River. Fish in the lower Clark Fork River can not pass upstream from Cabinet Gorge Dam, 30 km upstream from Lake Pend Oreille. They do have access to a number of tributaries that have little or no supersaturation, and to Lake Pend Oreille, an exceptionally large and deep lake of about 38,300 hectares and a mean depth of 164 m (maximum 351 m).

As identified by Weitkamp (1976) Bouck (1980) and others the hydrostatic compensation provided by water depth modifies or eliminates the biological effects of supersaturation. Gas bubble disease is the result of the "uncompensated hyperbaric pressure of total dissolved gases" (Bouck 1980). Therefore the behavior of fish that influences their depth distribution in the presence of TDG supersaturation determines their development or lack of development of gas bubble disease (GBD).

METHODS

The investigation of resident fish behavior in the lower Clark Fork River employed radio telemetry technology with tags capable of transmitting depth information to identify the vertical and horizontal distribution and behavior patterns of the tagged fish. Direct observation of fish was attempted in 1998 by biologist snorkeling along the shorelines in relatively low current areas. High levels of turbidity together with substantial depths made direct visual observation ineffective.

Resident fish were collected by boat electrofishing, radio tags were surgically implanted, and the fish released near their capture location following recovery from surgery (24-48 hrs). Healthy fish were selected and held over night at the Cabinet Gorge Hatchery for tagging the following day. Small numbers (2 to 19) of brown trout (*Salmo trutta*), bull trout (*Salvelinus confluentus)*, westslope cutthroat trout (*Oncorhynchus confluentus*), rainbow trout (*O. mykiss)*, whitefish (*Prosopium williamsoni*), largescale suckers (*Catostomus macrocheilus*), and northern pikeminnow (*Ptychocheilus oregonensis*) were tagged and tracked for periods of up to 49 days during the spill season.

Advanced Telemetry Systems depth-sensing radio transmitters used in the study consist of a pressure transducer, voltage regulator, and circuitry needed to alter the transmitting pulse intervals based on changes in pressure created by water depth. The pulse intervals decrease by increments of about 4 milliseconds (ms) with each depth increase of about 0.1 m. The pulse interval is updated from the pressure circuitry every 10 seconds. The pressure transducers were calibrated by the manufacturer to a maximum of 1.7 atmospheres, or the equivalent hydrostatic pressure at a depth of 17.5 m. Tags could not be detected at depths greater than about 12 m. Each transmitter operated on a unique frequency in the 150 MHz band, so that individual fish could be identified during tracking.

We used radio tags weighing between 2.2 and 5.5 g to allow tagging of various size fish. We followed the general rule of thumb that the tags not exceed 2% of the fish's body weight (Winter 1983). Tag weights vary with the number of batteries powering the tag, which in turn determines life of the tags. Estimated nominal battery life of the tags was 3 to 15 days, however, actual tag life is determined in part by the depth distribution of the fish because the pulse rate changes with depth. The pulse rate increases (shorter pulse interval) with increased depth depleting the battery faster. The smaller tags allowed the tagging of smaller fish.

Tagging began with each fish being placed in a holding tank containing approximately 0.04 mL/L concentration of clove oil. Anesthetized fish were identified to species and fork/total lengths measured. Tissue punches from the caudal fins of cutthroat, rainbow, and bull trout were acquired for later genetic analysis. Trout were also typically tagged with a passive integrated transponder tags (PIT-tag) for specific identification, if caught in subsequent electroshocking surveys. The fish were transferred to a surgical table equipped with a V-shaped trough to hold the fish upright with the ventral side exposed. A gravity fed irrigation system was used to flush the gills with a 0.04 mL/L concentration of clove oil in water to maintain anesthesia during the surgical procedures.

The tags were surgically implanted within the body cavity using methods described by Summerfelt and Smith (1990). Tags were inserted in the fish through a 1.5-2 cm incision made just to the side of the mid-ventral line and anterior to the pelvic girdle. A cannula was used to insert the antenna through the body cavity musculature posterior to the incision point (near the pelvic girdle) to allow the antenna to trail posteriorly. The incision was sutured closed and glued with veterinary tissue glue to seal the incision. Following surgery the fish were transferred to freshwater for recovery from the anesthetic. As soon as fish were able to maintain an upright position they were released into the fish ladder raceway and held for 24-48 hours prior to transporting and release at the original capture location.

The radio tagged fish were tracked by boat using a Lotek SRX-400 radio telemetry receiver and a Cushcraft P150-4, four-element Yagi antenna. Tracking typically began at least several hours after a fish was released and a fish was contacted as often as practical. The tracking crew traveled along the river by boat until a tagged fish was detected. Once a tag was detected, the boat was maneuvered upstream and to the side of the river where the fish was located. The motor was either shut off or put into neutral to minimize interference with the signal or disturbing the fish. As the boat drifted through the area, the location of the fish was determined at the point of maximum signal strength. Attempts were made to get as close as possible to the fish, to determine the approximate maximum distance the fish was from the nearest shoreline. However, the primary objective was to determine the depth distribution of the fish, so care was taken not to affect fish behavior.

Once the radio signals were strong enough to saturate the receiver, with an RF gain setting of about 50 dB, the pulse interval was recorded on data sheets. The pulse intervals were converted to depth estimates using calibration logs supplied for each tag by the manufacturer, which were adjusted for the altitude, average barometric pressure and water temperature at the project site. The tags were also calibrated in the field to verify the correction factors.

The daily tracking schedule varied over the years. Initially tracking was conducted throughout the day. In 2000 the tagged fish were typically tracked an average of about twelve hours per day, five days a week, concentrating on the dawn and dusk periods (4-10 am, 4-10 pm). The time, approximate river mile, estimated fish location relative to the shoreline, and specific shoreline landmarks were also recorded on the data sheets. A continuous TDG monitoring station was established near the Clark Fork Hatchery to provide detailed data on TDG fluctuations over time; previous monitoring has documented that TDG levels at that site are representative of the levels that occur in the river (Parametrix 1996).

The species, numbers of fish and size of fish tagged during May and June of each year are listed in Table 1. During the first two years we selected fish according to their general abundance with some emphasis on salmonid species. In 2000 rainbow trout were specifically selected because of the interest in this species and their general tendency to be present in relatively shallow water.

Table 1. Numbers and size ranges (mm) of resident fish tagged and tracked in the lower Clark Fork River.

Species	1998		1999		2000	
	No.	Length	No.	Length	No.	Length
Rainbow trout	2	682, 724	6	582-763	19	313-533
Brown trout	5	524-904	8	382-610	3	493-611
Cutthroat trout	3	703-883	5	224-723	6	300-403
Bull trout	1	764	3	384-564	2	403, 457
Mountain whitefish	1	642	3	624-723		
Northern pikeminnow	3	543-783	2	184, 284		
Largescale sucker	4	602-743	3	240-483		

RESULTS

Tagged fish were tracked as long as tags could be detected. The operation period of tags varied with the size of the tag, which is determined by battery size. Smaller tags (three and five day rated life) as well as larger tags (15 and 30 day rated life) were used to provide appropriate size tags for various size fish. In some cases smaller tags were placed in larger fish since tags were purchased long before the fish were collected.

Tags commonly were tracked substantially longer than the rated life span of the tags. Commonly fish were tracked from one to four times the nominal tag life and numerous detections recorded (Table 2). However, rainbow trout were generally detected for relatively short periods, substantially less than the nominal tag life, apparently due to their movement out of the lower Clark Fork River.

Table 2. Nominal tag life, average detection period (days), and mean number of detections of radio-tagged fish tracked in the lower Clark Fork River.

Species	Actual detection periods for nominal tag life				Mean No. detections
	3 Day	7 Day	15 Day	30 Day	
rainbow trout	5.3	6.7	2.7	-	11.7
brown trout	5.5	15.0	32.9	6*	55.6
cutthroat trout	4.7	8.3	13.0	-	19.4
bull trout	-	3*	35.5	29*	46.2
mountain whitefish	5.0	3*	NA	-	19.7
northern pikeminnow	16*	-	62.0	41.0	135.0
largescale sucker	14*	24*	39.2	-	95.1

* Values are for single tags.

Four of 23 tagged rainbow trout (17%) were detected in the tributary streams for periods of several hours to several weeks. Three other trout were undetected for periods of 4 to 20 days during the period that their tags were active. These fish are suspected of either entering a tributary or moving downstream to the lake during the monitoring period. Six additional fish disappeared from the river within two days of their release, and two others disappeared within about three days.   These eight trout were not subsequently detected, indicating they remained outside the survey area during the life of the tag. As these observations were unique to rainbow trout we conclude the fish were either in Lake Pend Oreille at depths below our detection capability, or in tributaries outside the survey area. About 73% of the tagged rainbow trout appear to have moved outside the lower Clark Fork River within several days following release.

A substantial number (43%) of the cutthroat trout appeared to migrate quickly to either Lake Pend Oreille or a tributary. Three of fourteen radio-tagged cutthroat trout were detected in areas other than the mainstem river for at least two days. Two additional cutthroat were detected in the river for no more than four hours suggesting that they also left the lower river. One of these fish remained at a specific location on the edge of the lake for a period of days indicating it may have died, and four were undetected following release. Two of the six tagged bull trout also migrated out side the lower river, one into the lake and one into a tributary. A third bull trout was not detected following release. Four of the brown trout left the lower river for 2-20days and returned for the remainder of the tag life. Two other brown trout were detected in a tributary for short periods.

DEPTH DISTRIBUTION

Median and average depth distributions (m) and distances over which the tagged fish were detected are listed by species in Table 3. These data indicate the fish of each species tended to remain at depths of two meters or more much of the time. Depths of two meters and greater provide hydrostatic pressure compensating for supersaturation of 120% or less as measured with reference to surface pressure. The northern pikeminnow had the deepest distribution of any species investigated with a media depth of 3.9 m. Other species, with the exception of rainbow trout had median depths of 1.7-2.4 m.

Table 3. Depth distributions (m) and distances ranged for tagged fish in the lower Clark Fork River.

SPECIES	Median depth	Average depth	Minimum depth	Maximum depth	Average median depth [1]	Median range (km)	Average range (km)
rainbow trout	1.3	1.5	0.0	6.1	1.8	5.5	6.1
brown trout	2.0	2.3	0.0	8.7	2.6	2.9	6.6
cutthroat trout	1.7	1.8	0.0	10.4	1.7	6.6	7.1
bull trout	1.8	2.2	0.0	11.8	2.2	7.7	7.7
mountain whitefish	2.0	2.0	0.1	4.3	1.7	8.3	8.3
northern pikeminnow	3.1	3.9	0.0	15.4	3.3	3.1	3.5
largescale sucker	2.0	2.4	0.0	11.4	2.3	6.1	6.3

[1] Average of median depths for individual fish.

However, rainbow trout had a median depth distribution of only l.3 m. These fish tend to avoid TDG supersaturation in the lower Clark Fork River by migrating rapidly through the area between Lake Pend Oreille and tributaries to the lower river, or from the hatchery to the lake.

HORIZONTAL MOVEMENTS

Most tagged fish were tracked in a downstream direction initially following release (Table 4). About 64% of the tagged fish initial moved downstream with the river current, while a small portion (18%) of the fish moved upstream immediately following release. Brown trout behavior was somewhat different in that the tagged fish were equally divided in initial upstream and downstream movements. A few (11%) fish initially remained near the release location and later moved either upstream or downstream, while others (15%) continued to move both upstream and downstream throughout the life of their tag. Only 3% of the fish remained in the immediate vicinity of the release location although nearly all were released close to their capture location.

Brown, bull, and cutthroat trout all tended to show a variety of movement patterns throughout the life of the tag. However, most rainbow trout initially (83%) moved downstream and most (73%) stayed downstream following their initial movement. Many of these fish either moved into Lake Pend Oreille or into one of the lower river tributaries following release. These movements of rainbow imply the trout were migrating through the lower Clark Fork between Lake Pend Oreille and tributaries, rather than residents of the lower river. Each of the five northern pikeminnow tagged showed nearly continuous movement both upstream and downstream following release. These pikeminnows remained within the lower river rather than moving into either the lake or tributaries.

Table 4. Direction of horizontal movement of fish equipped with radio tags (numbers of fish), lower Clark Fork River.

SPECIES	Little or none[1]	D.S.[2]	D.S. - U.S.[3]	D.S. - U.S.- Lake[4]	U.S.[5]	U.S. - D.S.[6]	None- U.S. or D.S.[7]	Multiple up & down[8]	Total fish
brown trout		4	2	2	2	2	1	3	16
bull trout	1		2	1			2		6
cutthroat		3	2	2	1	1	1	1	11
rainbow	1	16	2		1	2			22
largescale sucker		2			1		3		6
Mt. whitefish			1			1			2
No. pikeminnow								5	5
Total Movement	2	25	9	5	5	6	7	9	68

[1] Little or None = Remained near the release site.

[2] D.S. = Predominantly downstream movement

[3] D.S.- U.S. = First moved downstream and the upstream (sometimes only back to near the release point)

[3] D.S.- U.S.-Lake = First moved either up or downstream, then the reverse, eventually moved to the lake (sometimes returning)

[5] U.S. = Predominantly upstream movement

[6] U.S.- D.S. = First moved upstream and the downstream (sometimes only back to near the release point)

[7] None-U.S. or D.S. = Held near the release site for several days before moving up or downstream

[8] Multiple Up & Down = Moved back and forth throughout most of the monitoring period

DISCUSSION

Our observations indicate resident fish and fish migrating through the lower Clark Fork River are actually exposed to lower levels of total dissolved gas (TDG) supersaturation than would be expected based on laboratory observations. The behavior of these fish places them at depths and locations that reduce or avoid exposure to supersaturation. Occupying depths of several meters or more for a substantial portion of each day or movement into tributaries provides the reduction in exposure to TDG supersaturation. The observed behavior explains the relatively low rates of gas bubble disease (GBD) observed by Weitkamp et al. (in press).

It is obvious that fish remaining at depths of several meters or more, or moving into tributaries during periods of high TDG supersaturation will avoid or minimize development of gas bubble disease (GBD). The objective of this investigation was to determine the actual behavior of resident fish in a natural situation where high levels of TDG supersaturation frequently occur.

The depth distribution of resident fish in the lower Clark Fork River averaged more than

2 m for the species studied, other than trout. Rainbow trout had an average depth of only 1.5 m, however rainbows remained in the lower Clark Fork River for only brief periods of time. Cutthroat trout had an average depth of 1.8 m. These depths provide compensation for TDG supersaturation in the range of 120-130%. This explains the near absence of GBD in resident fish of the lower Clark Fork River during years when TDG supersaturation reached level of 120-130% of saturation (Weitkamp et al. in press).

We found trout to be highly mobile with many moving into tributaries or Lake Pend Orielle outside our detection area. Most of the rainbow trout quickly moved out of the lower Clark Fork River shortly following release. Contact was lost with most of the rainbow that were tracked to near the mouth of the lower Clark Fork indicating they moved into deep water of Lake Pend Oreille at depths beyond or capacity to detect their tags. Since nearly all these fish moved downstream shortly following release and detection was lost in the lower river we assume they moved to deep water in the lake where detection was not possible.

Movement of rainbow trout out of the lower Clark Fork River into tributaries or Lake Pend Oreille reduces or eliminates their exposure to supersaturation. The tributaries have only shallow water, but little or no supersaturation. The surface water of Lake Pend Oreille has moderate levels of supersaturation, however the fish in the lake appear to remain sufficiently deep to avoid biological effects of even extremely high levels of supersaturation. Many of the tagged cutthroat and bull trout also showed similar movements out of the lower Clark Fork River following release.

Failure to detect tagged fish once they entered the lake is interpreted as an indication the fish were too deep to be effectively detected by radio telemetry, although they may not be inhabiting great depths. Warner and Quinn (1995) tracked vertical movements of a small number of rainbow trout in Lake Washington. They found the trout spent about 90% of the time within 3 m of the surface, along with brief dives to mean depths of more than 6 m. Even 3 m of depth would compensate for TDG supersaturation of 130-140%.

Substantial numbers of the other salmonid species remained in the lower Clark Fork during the period of high TDG supersaturation providing potential exposure that could lead to biological effects. The depth distributions of these fish determined their actual exposure to TDG supersaturation. The combination of supersaturation level and duration of exposure at shallow depths, along with the frequency of and duration of compensatory depths determined the development of GBD in these fish. Few fish in the lower Clark Fork River developed any signs of GBD in most years (Weitkamp et al. in press).

Even those salmonids that tend to seek the cover of depth during daylight hours are likely to move into open shallow water during hours of darkness (Campbell and Neuner 1985, Thurow and Schill 1996, Jakober et al. 2000). Other species such as largescale suckers have substantial portions of their populations commonly in shallow water as evidenced by their abundance in electrofishing collections (Weitkamp et al. in press).

Our observations of the depth distributions of resident fish in the lower Clark Fork River indicates that most fish are spending sufficient time at depth to avoid GBD. Other fish that migrate through the lower river, such as rainbow and cutthroat trout, do not appear to commonly spend sufficient time in the Lower Clark Fork River to develop signs of GBD. Either movement into tributaries not having TDG supersaturation or to compensatory depths of Lake Pend Oreille allowed these fish to avoid the development of GBD.

The considerable movements of fish detected in our observations tend to support the concerns for the restricted movement paradigm raised by Gowan et al. (1994). Our observations of rainbow movements are the opposite of the lack of movement observed by Cagill (1980) in a small stream. Although we have no explanation for the quick and rapid movements of rainbow trout, their uniform movement out of the observation area indicates they were not permanent residents within the lower Clark Fork River. Average movements of 6-8 km for most of the species during the observation periods of weeks indicates an absence of permanent or long-term station by most of the fish in the lower Clark Fork River. Our observation of an average movement of 6.6 km for brown trout was similar to the movements of brown trout reported by Clapp et al. (1990).

ACKNOWLEDGMENTS

Avista Corporation funded this investigation. Study plans were reviewed and approved by the Water Resources Technical Advisory Committee and the Clark Fork Management Committee. Bill Harryman and Melo Maiolie from Idaho Fish and Game provided advice in the kokanee evaluations. Idaho Fish and Game provided cutthroat trout and facilities at the Cabinet Gorge Hatchery for the radio-tagging surgery and recovery efforts as well as supplied us with kokanee for the live-cage evaluations. Field staff who collected fish, implanted tags, and tracked fish included Eric White (Normandeau), Shaun Wilkinson, Ryan Weltz, Dmitri Vidergar, (Avista), and Jeff Osborn, Jennifer Weitkamp, Michael Burger (Parametrix).

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LIST OF FIGURES