EVALUATION OF THE EFFECTS OF DISSOLVED GAS SUPERSATURATION ON FISH AND INVERTEBRATES DOWNSTREAM FROM BONNEVILLE, ICE HARBOR, AND PRIEST RAPIDS DAMS, 1993 and 1994

by

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ABSTRACT

Dissolved gas supersaturation in excess of state and federal water quality criteria is commonly occurring in the Columbia and Snake Rivers in association with increased spill at dams. These increased spill levels are intended to provide safe passage of migrating juvenile salmon. During the period of high spill in 1993 and 1994, we monitored the prevalence of gas bubble disease (GBD) in resident fish and invertebrates. Sampling gear included 7.5-m 2-stick seines, 50-m variable-mesh beach seines, electrofishing equipment, hydraulic epibenthic pumps, Ponar bottom samplers, and plankton nets. In 1994, weekly observations of survival rates and changes in prevalence of GBD were made for fish held 4 days in ambient river water.

In 1993, sampling was limited to locations downstream of Bonneville from 27 April through 14 June. External signs of GBD were rare and indicated that low prevalence of GBD in 6 of the 20 species 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 . Dissolved gas concentrations at sampling sites averaged 112% of saturation, with a range from 103 to 122%; concentrations above 120% occurred upstream from RKm 179 from 11 May through 21 May.

In 1994, from 4 May to 25 August, we examined 2,082 salmonid fishes, 11,976 nonsalmonid fishes, and 4,133 invertebrates for signs of GBD. Signs of GBD were prevalent downstream from Ice Harbor Dam, but were rare in the other river reaches sampled. Downstream from Ice Harbor Dam on 9, 10, and 11 May, total dissolved gas (TDG) levels reached 136% of saturation and were higher than 130% for 7 to 11 hours each day. Signs of GBD were observed in 5 to 10% of resident fish captured during the month of May. Half of the 22 species captured displayed signs of GBD. When TDG levels at the sampling sites dropped to a daily average of 110% of saturation with peaks no higher than 115%, GBD signs among sampled fish disappeared. Signs of GBD were observed in only one species of fish captured downstream from Bonneville and Priest Rapids Dams, and in no fish captured upstream from Priest Rapids Dam. However, in those reaches, TDG levels of 120% of saturation were never exceeded at the sampling sites, and only occasionally exceeded in midriver. Signs of GBD among invertebrates collected from monitoring sites were few.

On weekly intervals through the spring and summer high flow period of 1994, fish were held 4 days in ambient river water. Impacts from GBD were dependent on the holding conditions and the dissolved gas concentration. When maximum dissolved gas levels reached

135% of saturation, salmonids restrained to the upper meter of the water column sustained severe mortality, but no nonsalmonids died. Fish held at 2-3 m and 0-4m of depth generally displayed a few signs of GBD, but sustained little GBD related mortality. At levels averaging slightly above 120% of saturation, GBD signs and GBD related mortality were variable, and probably influenced by previous exposure to high levels of dissolved gas of individual test fish.

The prevalence of GBD signs in juvenile salmonids sampled downstream from Bonneville Dam in 1993 and 1994 were not different from prevalences observed in large scale monitoring at Bonneville Dam.

INTRODUCTION

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

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

Through 1993, exceedance of 110% of saturation was not contested by water quality agencies. However, during 1994, it became necessary to obtain a temporary variance of the 110% saturation maximum standard from the Washington State Department of Ecology and Oregon State Department of Environmental Quality. To accommodate spillway passage of juvenile salmon, dissolved gas levels in tailraces at most dams on the lower Snake and Columbia Rivers were allowed to reach 120% of saturation during the period of spill. An intensified GBD monitoring program was instituted to evaluate the consequences of this action.

The objective of this study was to assess the impacts of ambient levels of gas supersaturated water on aquatic organisms in selected reaches of the Columbia and Snake Rivers heretofor not monitored for GBD.

METHODS

Sampling Locations And Methods

Weekly sampling for prevalence of GBD in salmonids, resident fish species, and invertebrates was conducted: in 1993, downstream from Bonneville Dam from RKm 229 to RKm 62; and in 1994, downstream from Bonneville, Ice Harbor, and Priest Rapids Dams (RKm 229-219, RKm 14-2, and RKm 600-593 respectively), as well as upstream from Priest Rapids Dam (RKm 652-641). The sampling effort encompassed the spring freshet and periods of spill managed for passage of juvenile salmonids.

Up to 100 juvenile salmonids and 100 individuals each of other aquatic species were sampled weekly in each river reach. Downstream from Bonneville Dam, fish sampling was primarily conducted using a 7.5-m 2-stick seine with 12.7-mm webbing. Two people pulled the 2-stick seine upstream along the beach, collecting fish from no deeper than 1 m. If there was sufficient depth in a sampling location, a 3.4-m-deep, 50-m variable-mesh beach seine was used for sampling. Electrofishing was the most effective means of collecting resident nonsalmonid fish species (target species) downstream from Ice Harbor Dam, downstream from Priest Rapids Dam, and in Priest Rapids Reservoir.

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

Benthic and epibenthic macroinvertebrates were collected from depths of up to 0.6 m using a hydraulic epibenthic pump and Ponar bottom samplers. A 0.6-m-diameter plankton net with 0.5-mm mesh was used to collect zooplankton samples near the water surface. These samples were washed with water through a 0.5-mm screen, and all macroinvertebrates were retained. We examined organisms immediately after collection with a dissecting microscope using 10- to 40-power magnification.

Net-Pen Studies

In 1994, weekly observations of survival rates and changes in prevalence of GBD were made for resident nonsalmonid species. Specimens were collected from each river reach, examined for prevalence of GBD, held in net-pens and cages for 4 days, and then reexamined for external signs of GBD. Hatchery-reared subyearling fall chinook salmon (*O. tshawytscha*) obtained from Bonneville Hatchery were also held in net-pens and cages at two sites: downstream from Bonneville Dam and downstream from Ice Harbor Dam. A subsample of 10 hatchery chinook salmon were examined more carefully for gas bubbles in the lateral line using a microscope with 15-power magnification. All mortalities were examined for internal signs of GBD.

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

Dissolved Gas Measurements

Total dissolved gas and water temperature were measured at the time of sampling at each location and at the net-pens using tensionometers[1] (D'Aoust et al. 1976). We attempted to measure dissolved gas concentrations in 4-hour increments during net-pen holding experiments. Means and ranges of TDG during 4-day holding periods were determined from 4-hour data records. Evaluation of accuracy was based on comparisons with Weiss saturometers.

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

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

RESULTS

1993

Three species of invertebrates and 17 species of fish were collected and identified during the study. The invertebrates examined were Asian clams (*Corbicula* spp.), crayfish, and dragonfly larvae (*Gomphus* spp.) (Toner and Dawley 1995). 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*), redsided 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 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. 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. Signs of GBD were not observed in the three species of invertebrates that we collected.

The spill regime at Bonneville Dam 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. The dissolved gas saturation levels at Warrendale OR. (the site of the COE Dissolved gas monitoring instrument) lagged behind the increase and decrease of spill levels at Bonneville Dam by approximately 2 hours. This diel fluctuation over 1-week periods is presented in Figure 1. 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 time period when most of the signs of GBD were observed.

1994

GBD in Fish and Invertebrate Samples

Downstream from Bonneville Dam, 1,282 salmonids, 4,955 nonsalmonids, and 3,928 invertebrates were collected for a total of 23 taxa of invertebrates and 22 species of fish (Toner et al 1995. Among all fish examined, only juvenile chinook salmon exhibited external signs of GBD: overall, 0.2% of these showed signs of GBD. Signs of GBD were seen only in early May when the highest TDG levels at sampling sites were measured.

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

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

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

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

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

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

GBD in Captive Fish Groups

Bonneville--Some signs of GBD were observed among captive fish in every 4-day holding period from 4 May through 10 June, when average TDG levels in the pens ranged from 114 to 117% of saturation. Most signs of GBD were observed among fish held near the surface (0-0.5 m). However, some signs were observed among fish in the 0- to 4-m-deep net-pen. Signs of GBD were primarily emboli in the lateral lines of hatchery salmon (up to 30%), but emboli were not seen consistently among test groups even when gas levels were similar. Subcutaneous emphysema between fin rays was observed less frequently (up to 20%), but prevelances were more consistent with TDG trends. The highest prevalence of subcutaneous emphysema was observed in the test conducted from 9 through 13 May, when gas levels peaked at 126.3% of saturation.

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

Ice Harbor--The highest prevalences of signs of GBD were observed during holding experiments conducted from 9 May to 13 May and 23 May through 17 June. Prevalence of subcutaneous emphysema between fin rays ranged from 12 to 50% for salmon held in the surface cages and from 0 to 37.5% for salmon held in the 0- to 4-m net-pen. Salmon held in the control cages at 1.5- to 2.5-m depths displayed these signs only during the 9-13 May test at 10% prevalence; on those days, TDG levels averaged 125% but reached a high of 135.1% of saturation.

Gas emboli in lateral lines were observed on 80% of the salmon from surface cages in two tests, but as in tests downstream from Bonneville Dam, these signs were not closely related to TDG levels. Prevelances of GBD signs among captive resident fish ranged from 0 to 40%. Even though these resident fish had been previously exposed to supersaturated conditions in the river, they generally displayed lower prevalence of GBD than salmon held 4 days.

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

DISCUSSION

Although little evidence of external signs of GBD was observed in fish sampled 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.

Comparison to GBD at Dams

In 1994, prevalence of external signs of GBD in juvenile salmonids seined from the river or held in net-pens downstream from Bonneville Dam was similar to that observed in salmonids collected by the Smolt Monitoring Program (SMP) at Bonneville Dam (Columbia Basin Fish and Wildlife Authority 1994). From 11 to 12 May, signs of GBD were observed in 1 to 2% of seined juvenile chinook salmon, whereas no signs were observed at Bonneville Dam.

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

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

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

GBD in the Hanford Reach

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

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

Comparison to 1974 GBD Study

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

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

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

SUMMARY AND CONCLUSIONS

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

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

In 1993 and 1994, no signs of GBD were observed in naturally rearing fall chinook salmon in the river reach near Locke Island. We believe that TDG was sufficiently dissipated in the 40 km of free-flowing river downstream from Priest Rapids Dam to provide relatively safe gas levels for resident fishes.

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