Some Effects of Excess Dissolved Gas on Squawfish, *Ptychocheilus oregonensis* (Richardson)

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ABSTRACT
In the spring of 1974, large numbers of squawfish were encountered in the Snake River between Lower Monumental and Little Goose Dams. Squawfish exhibited gas bubble disease symptoms within 1 week after the onset of 125 to 135% saturation. A 12-day bioassay in shallow tanks to determine tolerance levels and resistance times at various gas concentrations was conducted. We found squawfish to be similar to juvenile salmon and steelhead trout in their resistance to supersaturated concentrations of dissolved gas. Feeding response changed after stress to high concentrations of dissolved gas. Average daily food consumption of test groups decreased with increased supersaturation. Squawfish captured in the field during periods of high supersaturation were less abundant and only a small portion of them had been feeding compared with survey results taken during lower supersaturation. Nitrogen supersaturation could be an important factor in assessing the effects of predation on juvenile salmonid migrants in the Columbia River system.

Squawfish have attracted the interest of many investigators in the past, primarily because they have been regarded as an efficient predator. Our attention was focused on them as being one of the possible causes of mortality of seaward migrating juvenile salmon and steelhead trout in the Snake River.

In the spring of 1974 large numbers of squawfish were encountered in the Snake River between Lower Monumental and Little Goose Dams (Fig. 1). At this time, an abnormally high runoff occurred, resulting in high nitrogen gas concentrations of prolonged duration (Table 1). The squawfish exhibited gas bubble disease symptoms within 1 week after the onset of high gas saturation. Laboratory experiments and field observation were conducted to determine the tolerance of squawfish to supersaturation of dissolved gas and how it affected their food intake or predation rate. We wish to report on these aspects and discuss problems that may require further clarification.

Predation and eating habits have been examined by several investigators. Squawfish in the Columbia River were determined to be opportunists in their eating habits and, by and large, the availability of prey influences their selectivity of daily food intake (Thompson, 1959). Thompson found that approximately 63% had empty stomachs and only 7.5% showed any evidence of eating juvenile salmon. Hamilton et al. (1970), in the Lake Merwin investigation, found that 70% of the stomachs examined were empty, but concluded at the end of his study, that predation precluded the use of the Lake Merwin Reservoir as a rearing area for coho salmon. Brett and McConnell (1950) used an estimated consumption rate of 140 salmon fingerlings per squawfish per year, a figure which was accepted as reasonable, to account for calculated losses of sockeye juveniles from Lakelse Lake, British Columbia. If we use these figures for the Snake River during a 45-day juvenile outmigration, each adult squawfish might consume

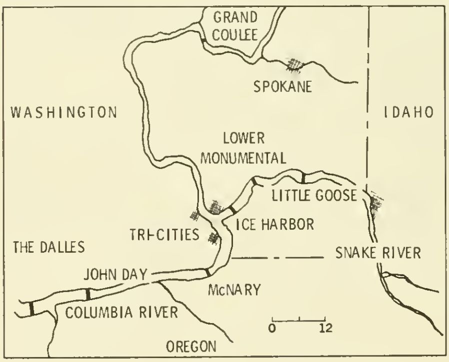

FIG. 1 Vicinity map showing location of Lower Monumental and Little Goose Dams.

Bentley, Dawley, and Newcomb: National Marine Fisheries Service, Seattle, Washington.

TABLE 1 Temperature, Dissolved Gases, Spill and Total Water Flow (in Thousands of c.f.s.) at Lower Monumental and Little Goose Dams from April to August, 1974. Data obtained by biweekly airplane flights and analyzed by staff in Seattle.

	Little Goose Dam forebay						Lower Monumental Dam forebay					
Date	Temp°C(F)	%O_2	%N_2	T.D.G.	Spill	Tot. flow	Temp°C(F)	%O_2	%N_2	T.D.G.	Spill	Tot. flow
4/19	8.3(46.9)	99.6	101.4	101.0	86.0	131.0	8.5(47.3)	117.8	122.1	120.9	83.0	150.0
4/23	9.6(49.1)	102.5	106.8	105.8	61.0	130.0	9.9(49.8)	130.8	134.6	133.3	59.0	126.0
5/7	11.6(52.9)	105.9	110.3	109.2	96.0	162.0	12.1(53.8)	130.8	135.8	134.2	95.0	164.0
5/21	11.4(52.5)	98.5	104.1	102.8	17.0	83.0	11.3(52.3)	114.2	121.5	119.7	15.0	80.0
6/4	12.2(54.0)	99.2	102.9	102.0	92.0	161.0	11.9(53.4)	127.9	141.1	137.7	90.0	159.0
6/19	12.8(55.0)	102.4	111.5	109.4	228.0	300.0	12.5(54.5)	128.7	143.8	140.0	220.0	294.0
7/2	16.9(62.4)	99.5	106.8	105.1	0.0	126.0	16.7(62.1)	124.6	131.8	129.8	66.0	133.0
7/16	17.4(63.3)	103.4	106.7	105.9	19.0	63.0	19.0(66.2)	102.4	106.4	105.5	3.0	68.0
7/30	24.5(76.1)	117.7	110.3	111.5	0.0	47.0	23.2(73.6)	110.3	106.7	107.2	0.0	44.0
8/13	21.7(71.1)	99.4	104.9	103.7	0.0	44.0	21.7(71.1)	101.8	105.8	104.9	0.0	43.0

17.4 salmonids causing a loss of 5.2 million fingerlings if a population of 300,000 squawfish exists for the stretch of the river between Ice Harbor to Little Goose Dam.

The effects of dissolved gas on squawfish had been examined by Meekin and Turner (1974) and Blahm (1974). Blahm's results indicate that squawfish were more resistant than juvenile salmonids when stressed with supersaturation. Meekin and Turner indicated slightly less tolerance than salmonids and that predation ability was substantially reduced when they were in supersaturated conditions. We attempted to place specific values on the dissolved gas tolerance of the squawfish, to substantiate and enumerate changes in the predation rate, and to discern if any correlations exist between laboratory experiments and field observations.

TECHNIQUES AND MATERIALS

Squawfish for our laboratory experiment in Seattle were captured in a Lake Merwin trap installed in the Palouse River arm at Lyons Ferry, Washington. This unit was identical to those described by Hamilton et al. (1970) in the Lake Merwin study in the Lewis River. Purse seining at Little Goose Dam was accomplished with a seine 15-ft deep and 525-ft long operated from a power-driven barge similar to that described by Durkin and Park (1969). This shallow net was employed because of the depth limitations near the navigation locks and spill gates where we concentrated much of our effort.

All squawfish were tagged with a Floy anchor tag, FD 67®, and released. Besides the tag, some were branded using the liquid nitrogen technique described by Mighell (1969); none were fin-clipped or operculum-perforated.

We purse seined at Little Goose Dam tailrace under the assumption that squawfish would be moving upstream to potential spawning areas of rip-rap dikes adjacent to the dam. In addition to learning something of their movements, we wished to gain some knowledge regarding the numbers of squawfish in that section of the river. Also, purse seining at the dam during and after spill might tell us whether there would be any change in behavior or response to high nitrogen levels. In this area, seining began on April 24 and concluded on August 8. Since we wished to tag and recover the fish in this area of the dam, we did not sacrifice the fish for stomach analysis but examined the stomachs by firmly pressing the lower ventral area and working forward to the pectoral area.

Water samples were taken biweekly by aircraft; dissolved gas values were determined in our Seattle laboratory by techniques described by Ebel (1969) and Beiningen and Ebel (1970).

Six laboratory tests were conducted where dissolved gas concentrations averaged 126.1, 120.4, 117.2 and 99.8% of saturation of total dissolved gas (T.D.G.). Average variation from the desired test concentration was ± 1.1% of T.D.G. Test duration was 12 days. Simultaneous replicates were made of tests at 117, 110 and 100% saturation.

All test tanks were 1.2 m in diameter with water depths of 25 cm (hydrostatic compensation 0.025 atm of pressure, or about 2.5% of saturation decrease). Water flow was maintained at 7.5 ℓ/min at 10° ± 1°C. Tests were conducted with about 10 fish per tank over 12 days starting April 17, 1974. Mean size of the test fish at introduction was 364 mm and 534 g. Test fish were starved for 16 days prior to testing. A sample population was fed to determine the maximum weight of food an unstressed fish might consume in a 2-week period. A mixed diet of live steelhead (average size - 21 g, 80 mm) and dead smelt (average size - 30 g, 170 mm) was used. On the basis of food intake of the sample population we established a daily ration for test groups of four dead smelt and one live steelhead fingerling. One-half of the smelt introduced as food were cut in half to accommodate the smaller squawfish.

RESULTS AND DISCUSSION

Laboratory Bioassay

Substantial squawfish mortality occurred in tests at 126, 120 and 117% saturation. One hundred percent mortality occurred in 20 hours at the 126% level; 60% loss occurred within the 12-day test period at the 120% level; and 32% at 117% saturation. Mortality from gas bubble disease did not occur at 110, 107 or 100% T.D.G. saturation. Lethal exposure times for 10 and 50% mortality (LE_{10} and LE_{50}) for squawfish are compared in Table 2 with LE_{10} and LE_{50} values established (Dawley and Ebel, 1974 and Dawley et al., 1975) for potential salmonid prey. It is evident that squawfish are somewhat more tolerant than juvenile steelhead and spring chinook, but have much less resistance than fall chinook fry.

Gas bubble disease signs were found in all fish exposed to 126, 120 and 117% T.D.G. saturations. Eighty-nine percent of the squawfish exposed to 110% saturation also had gross signs of gas bubble disease; one of ten fish exposed to 107% T.D.G. saturation exhibited signs. No signs were noted at 100% T.D.G. saturation (Fig. 2). Gross gas bubble disease signs included hemorrhage and subcutaneous blisters present over large areas of their bodies. All fish showing signs of gas bubble disease exhibited grossly distended blisters between the fin rays. Exophthalmia ("pop-eye") occurred in only two experimental fish. Gaseous emboli were noted in the blood vessels of at least one gill arch in all gas bubble disease mortalities. Emboli were also observed in the gills of all squawfish surviving the

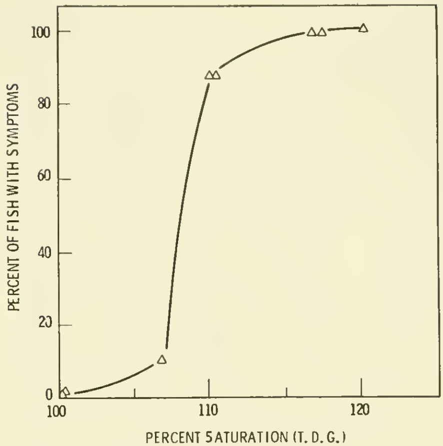

FIG. 2 Gas bubble disease symptoms in northern squawfish with increasing T.D.G. saturation.

120% saturation test and many surviving the 117% T.D.G. tests. Gill emboli were not detected in squawfish exposed to lower saturation.

Active feeding decreased from an average of 14.3 g food per fish per day for squawfish exposed to 100% saturation down to 2.3 g food per fish per day for squawfish exposed to 120% T.D.G. saturation (Fig. 3). These data indicate that feeding would be reduced by 50% at about 115% saturation. Below test saturations of 120%, squawfish showed a preference for live steelhead over the dead smelt (Fig. 4). The number of test days the ration of live steelhead was consumed was reduced about 40% when test fish were exposed to 117% T.D.G. saturation. Squaw-

TABLE 2 A Comparison of Lethal Exposure Times for Squawfish and Potential Salmonid Prey with 2.5% Hydrostatic Compensation

Percent saturation (T.D.G.)	Squawfish 364 mm 534 g 10°C		Juvenile steelhead 135 mm 20 g 15°C		Juvenile S. chinook 120 mm 15 g 15°C		Juvenile F. chinook 42 mm 0.4 g 10°C	
	LE_{10}	LE_{50}	LE_{10}	LE_{50}	LE_{10}	LE_{50}	LE_{10}	LE_{50}
110	> 12 day	>12 day	>35 day	>35 day	>35 day	>35 day	57 day	106 day
115							20 day	47 day
117	4.8 day	>12 day	26 hr	33 hr	19 hr	27 hr		
120	41 hr	9.7 day	10 hr	13 hr	11 hr	14 hr	7 day	22 day
126	19 hr	20 hr						

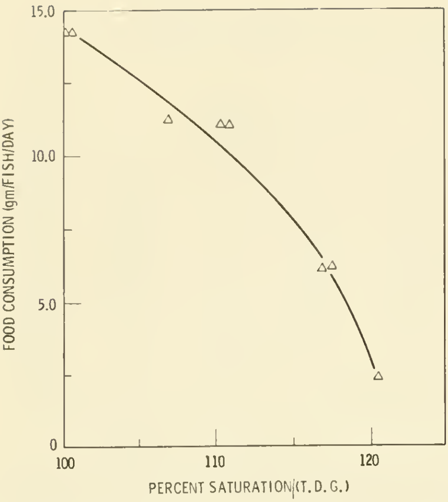

FIG. 3 Feeding inhibition of northern squawfish on a weight of food basis.

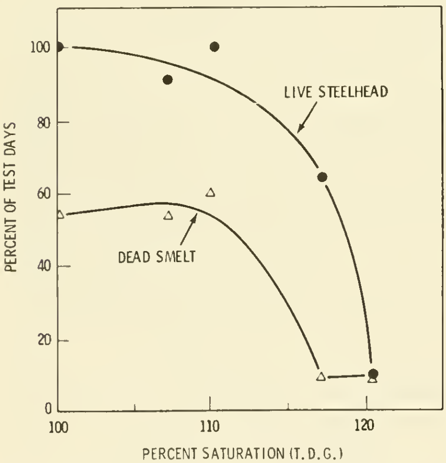

FIG. 4 Selective feeding inhibition of northern squawfish—% of test days when ration is completely consumed.

fish held at 120% saturation ate live steelhead only on the first test day.

Lethargy exhibited by the highly stressed fish may be of significance in regard to squawfish predation on juvenile salmonids migrating down the Columbia and Snake Rivers. However, the average water depth inhabited by squawfish may compensate for the effects of supersaturation. For example, in the reservoir of Lower Monumental Dam on the Snake River the dissolved gas level remained near 140% for an extended period of time this year and if the predatory squawfish had maintained an average daily depth of 2.76 m (9 ft), the effective saturation would have been 110%—low enough to allow the squawfish safe sojourn with no effective curtailing of predatory capacities. During experiments done earlier at the Prescott Field Station (Blahm, 1974), as well as those reported here, the squawfish tended to reside on the bottom of the tanks. However, this behavior may be an artifact due to the unnatural conditions of the laboratory test tanks. Nevertheless, the behavior of remaining on the bottom of the tanks changed the effective saturation value of the Prescott 1 m depth test from 119.7 to 109.1% T.G.P. and the 2.5 m test from 119.8 to 95.8% T.G.P. saturation. As a result, no mortality was reported in tests at Prescott, but gas bubble disease signs were apparent on all fish from the 1 m test after 35 days.

Seattle and Prescott data suggest that knowledge of the depth distribution is needed on the squawfish before its role as a juvenile salmonid predator can be correctly defined.

Merwin Trap - Purse Seine

Fish taken in our Merwin trap located in the Palouse River arm from January 1 to August 12, 1974, numbered 80,060 (Table 3). Squawfish totaled 16,626, with the majority taken in April, May and June, when dissolved gas saturation, temperatures and water flows were increasing (Table 1). Large numbers of squawfish may have concentrated in the Palouse River arm to escape the high dissolved gases in the Snake River. The Palouse River arm was sampled on July 2, 1974, and showed 106.8% nitrogen saturation at 21.7° C (71.1° F). Recaptures of marked fish released in the vicinity of the trap were 1,590, indicating that a high percentage remained in the area. Purse seining the navigation locks and spill area at Little Goose Dam captured 2,101 squawfish which were tagged and released. Fifty-five of those marked at the purse seine were subsequently recaptured in the seine at Little Goose Dam; and 97 that had been marked at the Merwin trap, over 11 miles downriver, were also taken in the seine at Little Goose Dam. Thirteen that were tagged at the dam appeared in the trap. One 370 mm squawfish marked at the trap made a round trip to the dam and back to the trap. Approximately 300 of the 1,590 recaptures at the trap were multiple recaptures. One 359 mm squawfish appeared in the trap 10 times.

Tagged recoveries showing movements between Lyons Ferry and Little Goose Dam indicate that high nitrogen values in surface waters appear to be

TABLE 3 Summary of Merwin Trap Catch at Lyons Ferry in the Snake River, January to August, 1974

Species	Jan. 30 to Apr. 4	Apr. 5 to May 28	May 29 to June 26	June 27 to July 24	July 30 to Aug. 12	Totals
Chinook, *Oncorhynchus tschawytscha*	1	1	4	0	0	6
Coho, *Oncorhynchus kisutch*	0	0	0	0	0	0
Sockeye, *Oncorhynchus nerka*	0	1	1	0	0	2
Steelhead, *Salmo gairdneri*	21	14	10	0	1	46
Shad, *Alosa sapidissima*	0	0	0	0	0	0
Squawfish, *Ptychocheilus oregonensis*	1475	6685	7944	240	282	16626
Whitefish, *Prosopium williamsoni*	6	16	0	0	0	22
Yellow bullhead, *Ictalurus natalis*	692	488	320	380	92	1972
Sucker, *Catostomus macrocheilus*	340	5288	14343	2617	4192	26780
Crappie, *Pomoxis annularis*	6273	11655	3764	3136	1347	26175
Yellow perch, *Perca flavescens*	125	123	21	138	20	427
Sunfish, *Lepomis* sp.	5	6	5	25	15	56
Shiner, *Notropis* sp.	51	58	73	15	6	203
Madtom, *Noturus gyrinus*	11	1	0	8	0	20
Bluegill, *Lepomis* sp.	18	6	42	17	9	92
Chiselmouth, *Acrocheilus alutaceus*	195	950	1211	64	182	2602
Carp, *Cyprinus* sp.	209	201	816	293	272	1791
Channel catfish, *Ictalurus punctatus*	59	504	884	1212	462	3121
Dolly varden, *Salvelinus malma*	4	1	1	0	0	6
Chub, *Hybopsis* sp.	20	0	1	0	0	21
Bass L.M., *Micropterus salmonides*	1	0	0	0	0	1
Bass S.M., *Micropterus dolomieui*	0	4	5	0	2	11
Lamprey, *Entosphenus tridentatus*	1	0	0	0	0	1
Sturgeon, *Acipenser* sp.	0	2	0	2	0	4
Peamouth, *Mylocheilus caurinus*	0	1	48	11	8	68
Sucker, Unident., *Catostomus* sp.	0	5	7	1	0	13
Total fish						80060

avoided during transience, but whether the squawfish were able to detect and avoid this area is unknown. The depth they normally inhabit may be sufficient to adequately compensate for the levels of supersaturation which occurred.

Length frequencies of those taken in the trap were different from those captured in the purse seine. In Fig. 5 a bimodal frequency is shown for fish sampled at Little Goose Dam in July and August with the lesser mode which is similar to the length frequency of fish sampled at the trap (Fig. 6). In the upper mode a group of squawfish, between 300 and 460 mm, had not been encountered before, suggesting that they may represent an entirely different population. One population may be reservoir spawners and the other tributary spawners. We have had tags turned in from the Palouse and Tucannon Rivers, the mouth of the Snake River and the Columbia River at Kennewick, Washington.

Purse Seine - Feeding

Purse seine catch at Little Goose Dam is shown in Table 4. When dissolved gas saturation was high, 176 squawfish were taken; five showed evidence of feeding. The numbers of squawfish taken per purse seine set were 11.7, indicating that there were few available. When dissolved gas saturation returned

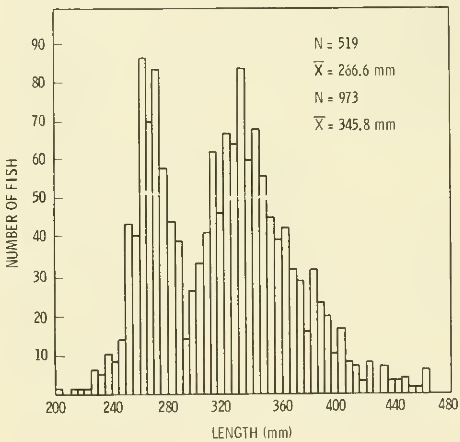

FIG. 5 Bimodal length frequency of squawfish taken by purse seine in the tailrace at Little Goose Dam from July 31st to August 8, 1974.

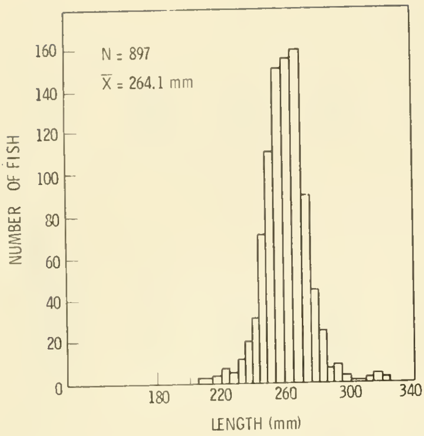

FIG. 6 Length frequency of squawfish taken in Merwin trap at Lyons Ferry in June, 1974.

TABLE 4 Purse Seine Results From Catches in the Tailrace of Little Goose Dam, 1974

Date		Sets	Sample size	Food
April	24	2	3	none
	25	4	26	1 unident.
May	3	1	22	none
	16	2	12	none
	30	3	17	2 unident.
	31	2	18	none
July	12	1	78	2 unident.
		15	176	5
		11.7 per set		
July	17	2	26	lamprey
	18	3	398	lamprey
	31	4	125	lamprey
August	2	1	542	lamprey and
	6	1	699	unident.
	8	1	145	fish
		12	1935	
		161.2 per set		

to normal, catches increased to 1,935 in 5 days of seining with an increase to 161.2 fish per set. All fish checked in the latter sample showed evidence of feeding heavily on lamprey ammocetes *Entosphenus tridentatus*, (Gairdner).

We might interpret the presence or absence of squawfish in the tailrace at Little Goose Dam as being influenced by high dissolved gases. Saturation in the spill and adjacent areas around the dam tended to keep squawfish away; and after gas saturation returned to normal they moved in to feed on whatever was available, which was mainly lamprey ammocetes. On the other hand, it is possible that large numbers of squawfish may have been present, but below the depth of our net where they would also be at sufficient depth to compensate for gas supersaturation and thus be safe from the disease. We do not know if they are at this depth. Thus, what appeared to be a response to high nitrogen levels could be the result of normal behavior patterns in the vicinity of spill gates and turbine discharge draft tubes at dams. It is evident, however, that those squawfish taken during high dissolved gas saturation were not effective predators.

CONCLUSION

Laboratory studies indicated that adult squawfish are susceptible to supersaturation of atmospheric gas at or exceeding 117% and exposure to these levels significantly reduced their food intake.

Field studies indicated that exposure of squawfish to supersaturation could be an important factor in assessing the effects of predation on juvenile salmonid migrants in the Columbia River but more information is needed on their movement, behavior and depth distribution before an accurate assessment can be made.

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