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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

Immobilization of Fingerling Salmon and Trout by Decompression

DOYLE F. SUTHERLAND

SEATTLE, WA
March 1972

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Immobilization of Fingerling Salmon and Trout by Decompression

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ABSTRACT

Laboratory experiments revealed that some chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) fingerlings are immobilized when decompressed from atmospheric pressure to high negative pressures. About 69% of the chinook salmon were partially or completely immobilized at 71 cm of mercury vacuum, 48% at 61 cm, 17% at 51 cm, and none at 41 cm. The effects developed rapidly, peaking 5 min after exposure. The coho salmon, in comparison, were less severely affected. Only 9% were immobilized at 71 and 61 cm of mercury vacuum (reached 10 min after exposure), 2% at 51 cm (5 min after exposure), and none at 41 cm.

Studies (with coho salmon and rainbow trout [*Salmo gairdneri*]) to determine the effects of decompression within a turbine of a dam did not provide conclusive results. However, some fingerlings caught in the tailrace immediately after their release in the turbine intake were immobilized. Exposure to negative pressure below turbine runner blades is one possible cause of immobilization.

INTRODUCTION

Many fingerling salmon and trout are injured or killed by physical contact with turbines and other structures within dams. Others are believed to suffer shock or death from severe pressure changes encountered during passage through dams (Schoeneman, Pressey, and Junge, 1961; Cramer and Oligher, 1964). Immobilized fingerling salmon and trout have been observed in turbine discharges of high and low dams on the Columbia and Snake Rivers. The present study, conducted in a laboratory and at Ice Harbor Dam, was undertaken as a result of these observations and examines the role of decompression as a possible cause of immobilization.

The Kaplan turbines at Ice Harbor Dam have an area of low negative pressure below the blades that theoretically averages about one-half atmosphere (38 cm of mercury vacuum) when the turbines are operated at rated capacity.[1] The actual level of negative pressure below the turbine blades is not known but must be considerably greater than the 38 cm theoretical average.

[1] Personal communication, S. Scott, U.S. Army Corps of Engineers.

It is also known that decompression to levels present in the turbines can be harmful to juvenile Pacific salmon. In a study of the effects of negative pressure on fingerling chinook salmon, Holmes and Donaldson[a] found that test fish suffered an average of 3.5% mortality when decompressed from 18 psi to —2 psi. Muir (1959) reported that fingerling coho salmon exposed to negative pressures of 12.7-73.7 cm/Hg for 0.1-2.3 sec appeared to be stunned momentarily but concluded that decompression to partial vacuum was not likely to kill the fish unless accompanied by cavitation. Harvey (1963) concluded from his studies and comprehensive review of the literature that the effects of decompression depended on the condition of the fish and physical factors in the environment as well as on the magnitude of the vacuum.

Immobilized fingerling salmon and trout were first observed at Ice Harbor Dam in 1966. Marked juvenile coho salmon and rainbow trout were released in a turbine intake and recovered in a funnel net attached to the draft tube exit. Some of the fish recovered swam normally; others were dead or in distress. Either the turbine or net could conceivably have produced the effects observed. Therefore, laboratory experiments were conducted to isolate and examine the effects of pressure change alone. The present paper reports the results of this research and subsequent observations of immobilized fish at Ice Harbor Dam.

METHODS AND MATERIALS

Laboratory Study

In this study chinook salmon fingerlings were substituted for rainbow trout as the latter species was not readily available. The chinook salmon fingerlings were downstream migrants caught in the gatewells of McNary Dam, Umatilla, Oreg. The coho salmon were nonmigrants taken from the White Salmon Federal Hatchery, White Salmon, Wash. All fish were transported to the test site by tank truck and held in a fish-holding facility (described below) for at least 2 days before they were used in decompression tests. Fork lengths of the two lots of fish were approximately the same; the chinook salmon ranged from 119 to 180 mm and the coho salmon from 135 to 190 mm. The slight size difference is believed to have had little or no influence on the comparative response of the two species to negative pressure.

The experimental apparatus consisted of two main components: (1) the fish-holding-recirculating system and (2) the pressure chamber-vacuum system. The basic arrangement (except for the vacuum pump and filter) is illustrated in Figure 1. A round wooden tank served as the holding facility. Water from the water main of Pasco, Wash., treated with sodium thiosulfate to neutralize the chlorinity, was continuously recirculated through a sand and charcoal filter and aerated by a diaphragm compressor. The water temperature was maintained at 9.0° C ± 0.5° C by a portable refrigeration system.

The pressure chamber was built from a 129.4-cm length of heavy-duty iron pipe, 30.5 cm in diameter. End plates of clear plastic, 2.5 cm thick, permitted observation of the test fish. Access to the chamber was gained through a port made from a 10.2-cm pipe sleeve fitted with a flange and cover plate. Additional sleeves provided plumbing attachments for water intake and discharge lines, air exhaust port, pressure gauge, and vacuum line. A 3,785-liter (1,000-gallon) tank served as a vacuum reservoir and was connected to the pressure chamber by a rubber hose 1.9 cm thick. The vacuum was applied by activating a hand-operated, 2.5-cm ball valve on the chamber end of the hose.

The amount of negative pressure applied to the chamber was controlled by evacuating the reservoir to the desired level as indicated on a gauge. A second gauge plumbed into the chamber monitored the pressure change. The vacuum was relieved by closing the vacuum line valve and venting the chamber by opening a second .6-cm ball valve.

About 1 sec was required to obtain 61 cm of mercury vacuum in the chamber when it was filled with water; 2½ sec were required to reach 71 cm of mercury vacuum because of the large amount of dissolved gasses liberated by the low negative pressure. At all negative pressures, it took one-half second to relieve the vacuum by opening the relief valve and closing the vacuum line valve.

[a] Holmes, H. B., and I. J. Donaldson. A study of the effect of pressure changes upon salmon fingerlings as applied to passage through spillway at Mayfield Dam, Cowlitz River, Wash. (Unpubl. manuscr., 18 p.)

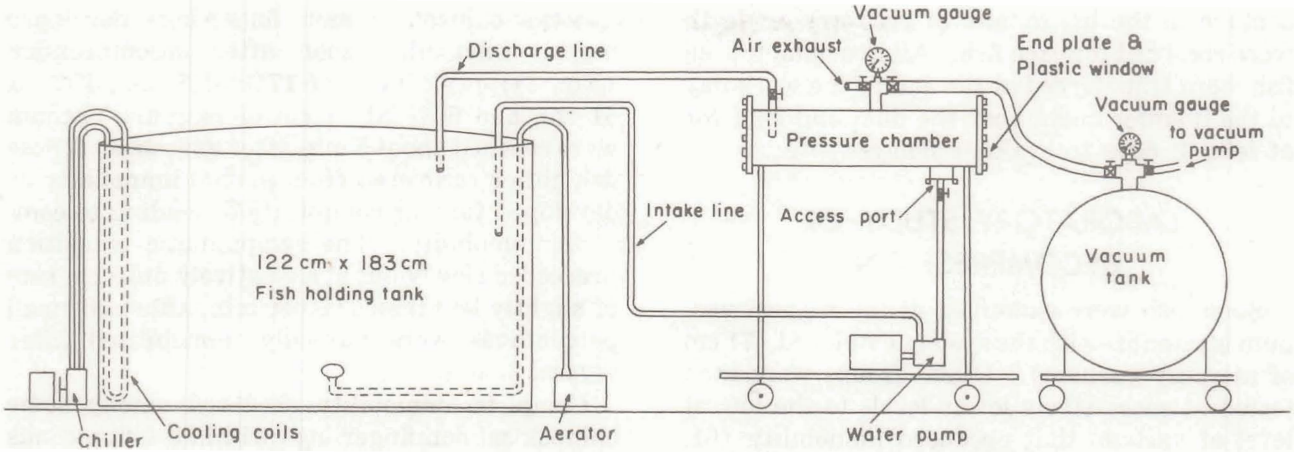

Figure 1.—Fish holding-recirculating system and pressure chamber vacuum system.

All test fish were held in the laboratory holding facility for a minimum of 2 days and in the pressure chamber for 1 hr before testing. After exposure to negative pressure, the fish were held in chambers for observation for as long as 1.5 hr, then transferred to the holding facility for final observation at the end of 24 hr. Water from the holding facility was circulated through the chamber at atmospheric pressure before and after each test.

Counts were taken of the numbers of fish partially immobilized, completely immobilized, and dead during the following periods after exposure: 5, 10, 20, 30, 40, 50, 60, and 90 min and 24 hr. Partially immobilized fish were recognized by their feeble efforts to swim; completely immobilized fish were identified by spasmodic movements or absence of movement other than respiratory. Those fish showing no evidence of opercular movement were considered dead, subject to later verification.

Each treatment was repeated three times on different groups of each species, for a total of six tests at each vacuum level. The number in each test averaged 16 for wild chinook salmon and 23 for the hatchery coho salmon for a total of 151 chinook and 216 coho salmon. The response of the test fish to decompression was computed from the three tests at each negative pressure and expressed as an average response. The order in which the fish were tested was dictated more by availability than by design. Generally the testing proceeded from the highest vacuum level to the next lower level.

Ice Harbor Dam Study

The coho salmon and rainbow trout tested in the turbines at Ice Harbor Dam had been reared in hatcheries to about 100-127 mm long. They were transported to temporary holding tanks near the dam a few days before the test to permit them to acclimate to Snake River water. Each fish was marked with a cryogenic brand to identify it as to time and place of release. A total of 5,408 coho salmon and 2,291 rainbow trout were branded and released in the turbines in 11 tests that began 11 October and ended 30 November 1966.

The test equipment used for studies of fingerling mortality in turbines was described by Long and Marquette (1967). It consisted of three basic components—a release hose extending from the deck of the dam to the turbine intake, a funnel net attached to the draft tube exit, and a recovery barge secured to the cod end of the net. A trough with several screened compartments was placed on the barge to hold immobilized fish for observation.

The test fish passed through a turbine that was being operated at rated or overload capacity. The first of the fish usually arrived at the barge within 3 min and the majority within 20 min after release. Those fish with characteristic symptoms of immobilization associated with decompression, yet apparently free of net or turbine injury, were immediately put into individual holding compartments for further observation. The times of release in the turbine intake, of capture in the barge, and of recovery or death were recorded for each fish. All live immobilized fish were transferred at the end of the work day to the holding tanks near the dam and held for at least 3 days to evaluate delayed effects.

LABORATORY STUDY OF DECOMPRESSION

Some fish were examined at the highest vacuum attainable with the system employed (71 cm of mercury vacuum). Other groups were then tested at successively lower levels to the lowest level of vacuum that produced immobility (61, 51, and 41 cm of mercury vacuum). For valid comparison of the laboratory results with those in the field, it was desirable to simulate field conditions by decompressing the fish as rapidly as when passing a turbine (one-half second or less). In exploratory trials with a small pressure chamber (10.2 × 121.9 cm), a high level of negative pressure could be achieved in a fraction of a second. The test fish, however—particularly the wild chinook salmon—did not appear to acclimate to the restricted environment. Subsequently, a larger pressure chamber (30.5 × 144.8 cm) was used, although the time required to reach high negative pressures was increased slightly.

The term "precondition" as used here means allowing the fish time to readjust the gas volume of the swim bladder to achieve neutral buoyancy with respect to the water density at atmospheric pressure in the excitement of being caught and transferred to the pressure chamber. Harvey (1963) described this behavior as a fright reaction whereby fish force gas from the swim bladder out through the pneumatic duct, decreasing buoyancy and facilitating escape by descent to greater depths. In the tests this behavior was more pronounced among wild chinook salmon than among hatchery coho salmon. Immediately after being placed in the chamber, the fish descended to the bottom where they remained relatively motionless. The hardy individuals generally swam to the surface after about 5 min, gulped air, returned to the bottom, and repeated the process until neutral buoyancy was established. About 1 hr was required to reequilibrate all members of a test group; this amount of time was subsequently adopted in the standard test procedure.

Some chinook salmon fingerlings developed partial immobility soon after decompression (Fig. 2); peak levels of 17% at 51 cm, 43% at 61 cm, and 60% at 71 cm of mercury vacuum were reached about 5 min after exposure. These fish either recovered from partial immobility or developed further complications leading to complete immobility. The symptomatic transition proceeded slowly but at a relatively uniform rate of slightly less than 1% per min, although small percentages were partially immobilized after several hours.

Complete immobility occurred among some chinook salmon fingerlings within a few seconds after exposure to 61 and 71 cm of mercury vacuum. Others developed the condition after several minutes of partial immobility (peak percentage 60 min after exposure to 61 cm and 30 min after exposure to 71 cm). None were completely immobilized by 51 cm of mercury vacuum. Most fish died that had developed complete immobility after several minutes of partial immobility. The percentages of deaths from expo-

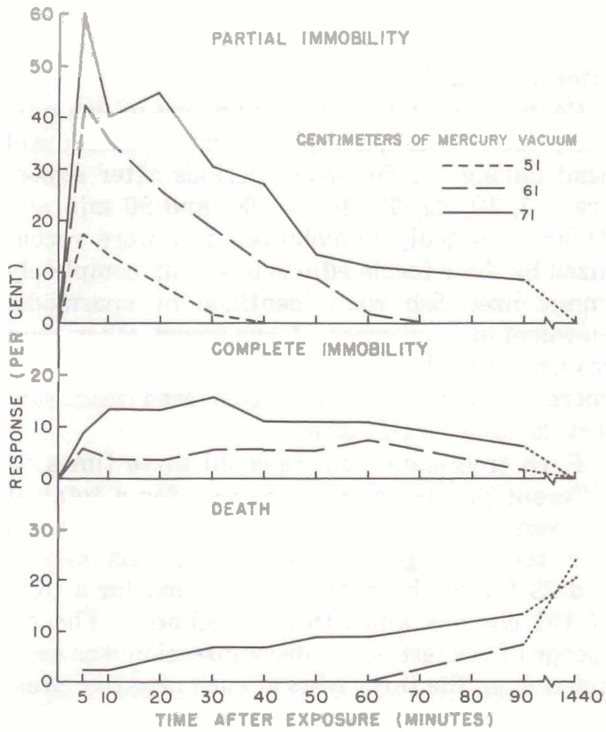

Figure 2.—Chinook salmon fingerlings partially immobilized, completely immobilized, or dead after exposure to various levels of negative pressure, by time after exposure.

sure to the higher negative pressures were 24% at 61 cm and 20% at 71 cm mercury vacuum.

The response of coho salmon fingerlings to decompression is shown in Figure 3. Symptoms of partial immobility developed in 2, 8, and 5% of the fish decompressed at 51, 61, and 71 cm of mercury vacuum, respectively. Ten minutes were required for development of the symptoms, compared to 5 min for the chinook salmon. No fish were completely immobilized after exposure to 51 cm of mercury vacuum; peak percentages were only 2% at 61 cm of mercury vacuum and 5% at 71 cm. Only 3% died from exposure to 71 cm.

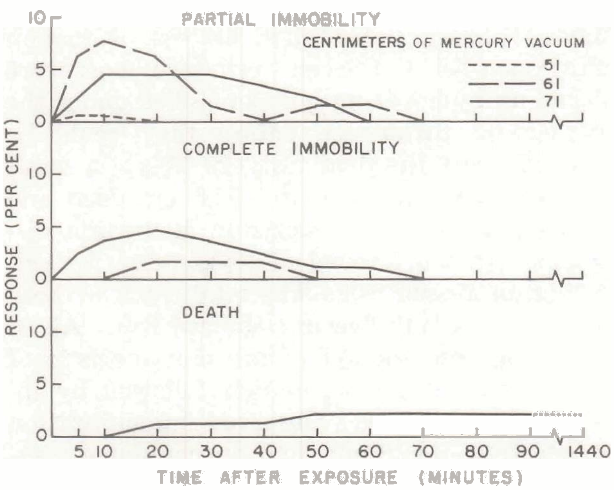

Figure 3.—Coho salmon fingerlings partially immobilized, completely immobilized, or dead after exposure to various levels of negative pressure, by time after exposure.

Wild chinook salmon were more susceptible to the effects of decompression than were hatchery coho salmon. The difference between species varied with level of vacuum; the greatest difference occurred within 5 min after exposure to 71 cm of mercury vacuum, when 69% of chinook salmon were either partially or completely immobilized as compared with 6% of the coho salmon. At 41 cm of mercury vacuum, no response to decompression was observed for either species.

The duration of exposure to negative pressure, or the rate at which fish subjected to reduction from atmospheric pressure to a specific level of negative pressure, probably influenced the absolute if not the relative results. Holmes and Rucker (cited by Holmes and Davidson, see footnote 2) found that chinook salmon fingerlings lived if allowed 1 sec to adjust to decompression from 40 psi to atmospheric pressure. In the present tests, 2.5 sec were required to reach 71 cm of mercury vacuum from atmospheric pressure and another 0.5 sec to relieve the vacuum. The test was executed in slightly less time at 51 and 61 cm of mercury vacuum.

IMMOBILIZED FINGERLINGS BELOW ICE HARBOR DAM

During the turbine studies at Ice Harbor Dam, recovered test fish were closely observed for symptoms of immobilization similar to those manifested by fish decompressed in the laboratory. The first immobilized fish were seen on 4 November during the fourth test (Table 1). On

Table 1.—Duration of immobilization of individual coho salmon and rainbow trout fingerlings recovered in the funnel net at Ice Harbor Dam, 4 November - 6 December 1966.

Date 1966	Species	Time from release in turbine to capture in funnel net	Time fish was immobilized: Observed	Time fish was immobilized: Estimated	Time from release in turbine to recovery from immobilization	Condition of fish after 3 days
		min	*min*	*min*	*min*	
4 Nov.	Coho	6	4	9	10	Alive
	Coho	6	62	67	68	Alive
16 Nov.	Rainbow	20	29	48	49	Alive
18 Nov.	Rainbow	22	[1]	[1]	[1]	Alive
22 Nov.	Rainbow	41	[1]	[1]	[1]	Dead
	Rainbow	43	[1]	[1]	[1]	Dead
30 Nov.	Rainbow	18	77	94	95	Alive
2 Dec.	Rainbow	10	13	22	23	Alive
6 Dec.	Rainbow	6	14	19	20	Alive

[1] Remained immobilized for several hours.

that date two coho salmon that had behaved identically to fish immobilized by decompression were caught 6 min after release in the turbine. They were quickly removed to individual holding pens, where one recovered within 4 min and the other within 62 min. The minimum travel time from release point to the barge was about 3 min; 1 of the 3 min was required for travel from the release point to the area of negative pressure below the turbine blades. One of the coho salmon was thus immobilized for a maximum of 9 min and the other for 67 min after passing the turbine blades. The recovery times of both fish were within the range for recovery from immobilization established in the laboratory. The two fish were transferred later in the day to the shore holding tank for observation of post immobilization effects. Recovery was evidently complete, for no adverse effects developed within 3 days.

Hatchery-reared rainbow trout were used in the seven tests that followed (Nos. 5-11); immobilized fish were found in six (Table 1). The relatively high frequency of recovery of affected fish suggests that either rainbow trout were more easily immobilized than coho salmon or that sampling efficiency increased with time. The former appears more likely—the three completely immobilized trout caught in tests 6 and 7 (November 18, 22) remained immobilized several hours. The exact time of their recovery or death was not determined. They were still immobilized when transferred from the barge to the holding tank late in the day. One recovered during the night and was alive 3 days later; the other two died during the night.

The four immobilized trout caught in tests 5, 9, 10, and 11 (16 and 30 November; 2 and 6 December) recovered on the barge while under observation. At most, they were immobilized from 19 (test 11) to 94 min (test 9) after passing the turbine blades. The minimum period of immobilization ranged ...... 13 (test 10) to 77 min (test 9). The four fish survived a 3-day holding period. The one caught in test 11 was alive and evidently normal after 30 days of observation for possible development of latent lethal effects.

Although few immobilized fish were caught in the turbine discharge, the small catch assumes greater significance when the methods of capture are considered. Of the total turbine discharge screened by the funnel net, slightly less than 1% entered the recovery barge; the rest filtered through the meshes of the net. An estimated 18% of the test fish released in the turbine were killed by impingement against the net and a much higher percentage injured by physical contact.

For immobilized fish to reach the recovery barge uninjured (not lacerated, descaled, etc.), they would have to be passively transported the length of the net by that flow directed toward the cod end.

Because the net may have caused immobilization by impingement, it was highly desirable to obtain samples of immobilized fish in the general area occupied by the net in the 1966 tests. Field parties with long-handed dip nets cruised the area in boats just after releases in April and May 1967 to search for fish in distress. Although many such fish were seen to surface, most were picked up by hovering gulls or pulled under the surface by turbulence before they could be reached. For the final test (10 May), a small inclined-screen scoop trap (50.8 cm deep and 121.9 cm wide) was anchored in the turbine discharge. It, too, proved of little value for collecting distressed fish. The total catch by both methods was only five immobilized fish. All of them displayed the symptoms characteristic of decompression, erratic motion followed by inactivity and sinking. Observed immobilization ranged from 2 to 6 min, and the computed maximum period of immobilization ranged from 6 to 18 min (Table 2).

Inherent in this study is the assumption that immobilization was due to decompression. The assumption is supported by laboratory experi-

Table 2.—Duration of immobilization of individual coho salmon fingerlings caught by dip net and scoop trap in the turbine discharge, 14 April - 10 May 1967.[1]

Date 1967	Time from release in turbine to capture in dip net and scoop trap	Time fish was immobilized: Observed	Time fish was immobilized: Estimated	Time from release in turbine to recovery from immobilization
	min	*min*	*min*	*min*
14 April	3	5	7	8
	5	2	6	7
21 April	14	5	18	19
10 May	7	4	10	11
	11	6	16	17

[1] All fish survived a 3-day holding period.

ments in which fingerling chinook and coho salmon were immobilized by exposure to negative pressure and by two items of indirect evidence: (1) regions of negative pressure within turbines and (2) immobilization of some fingerling salmon and trout after passage through turbines. The assumption, however, cannot be tested in situ, and some (if not all) of the fish may have been immobilized by factors other than decompression.

Because of the limited sampling, the data are of little analytical value but suggest that significant numbers of fish passing through a turbine are immobilized by physical forces in the turbine. Those fish that experience sublethal immobilization must surely contribute indirectly to the total loss at dams. At a river velocity of 1 m per sec, 10 min of immobilization would expose fish to predation for more than one-half kilometer. An accurate measure of total mortality due to turbines, then, requires an evaluation of direct and indirect losses. It may best be derived by determining the number of survivors passing a point several kilometers downstream from the dam.

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