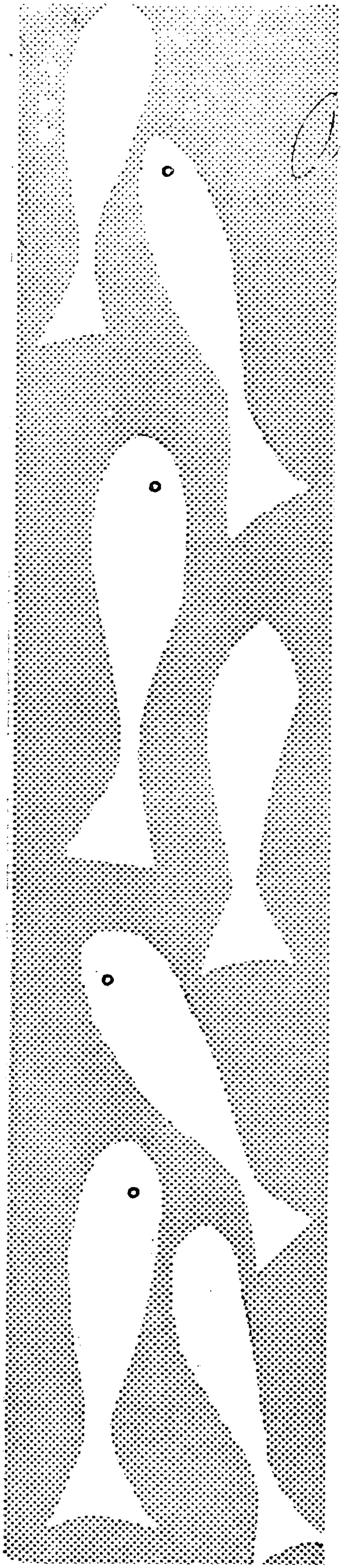

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COLUMBIA RIVER THERMAL EFFECTS STUDY

SURVIVAL TIMES OF JUVENILE SALMONIDS EXPOSED TO WATER TEMPERATURES CAUSING THERMAL "SHOCK"

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INTRODUCTION

During their migrations, anadromous fish in the Columbia River may encounter heated discharges. Coutant (1969a) showed that at Hanford, Washington, a heated discharge produced a thermal plume 17 C above ambient river temperature. Adults may be able to detect and avoid such discharges[1/]. Young fish, however, might involuntarily pass into these flows; their survival would depend on the temperature of the discharge and how long the fish remained in the hazardous zone. A study was initiated in 1968 to examine effects of temperature level and exposure time on juvenile salmonids in relation to heat death.

PHYSICAL TEST EQUIPMENT

The test facility (fig. 1) and physical equipment utilized for this study are described by Snyder, Blahm, McConnell (1970) and Blahm and McConnell (1970a, 1970b). Heated and chilled water was supplied to 188-liter test tanks where it was mixed to provide the required test water temperatures. The test tanks were clear acrylic plastic which allowed the observer maximum visibility.

TEST FISH

Test fish were captured either in the Columbia River near the test facility (fig. 2) or obtained from hatcheries in Washington and

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1/ C. R. Weaver, BCF, Seattle, Washington. Progress Report No. 137, Dec. 1966. Research on fishway problems conducted at the Fisheries Engineering Laboratory at Bonneville Dam under Contract No. DA-35-026-25142 with the U.S. Fish and Wildlife Service.

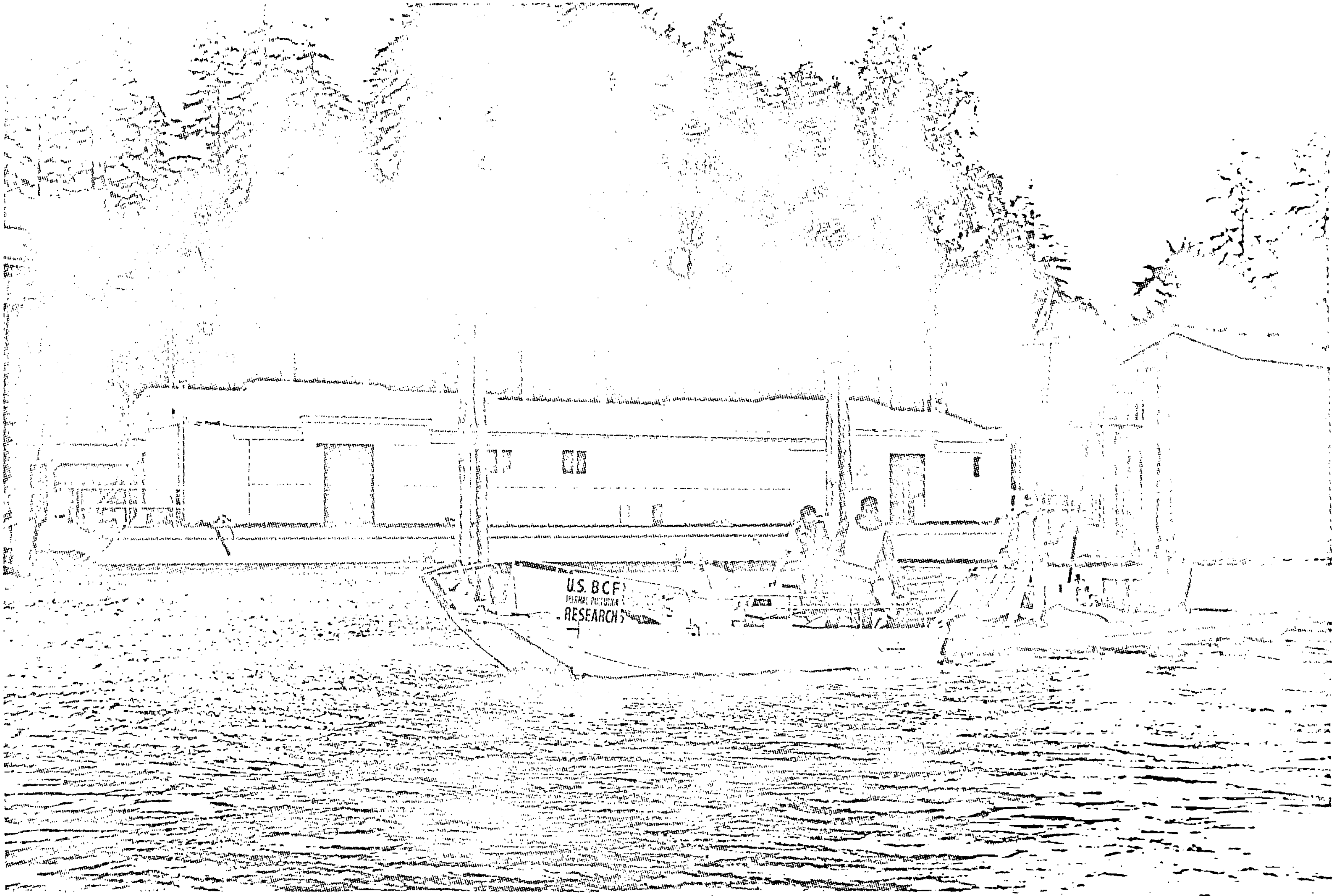
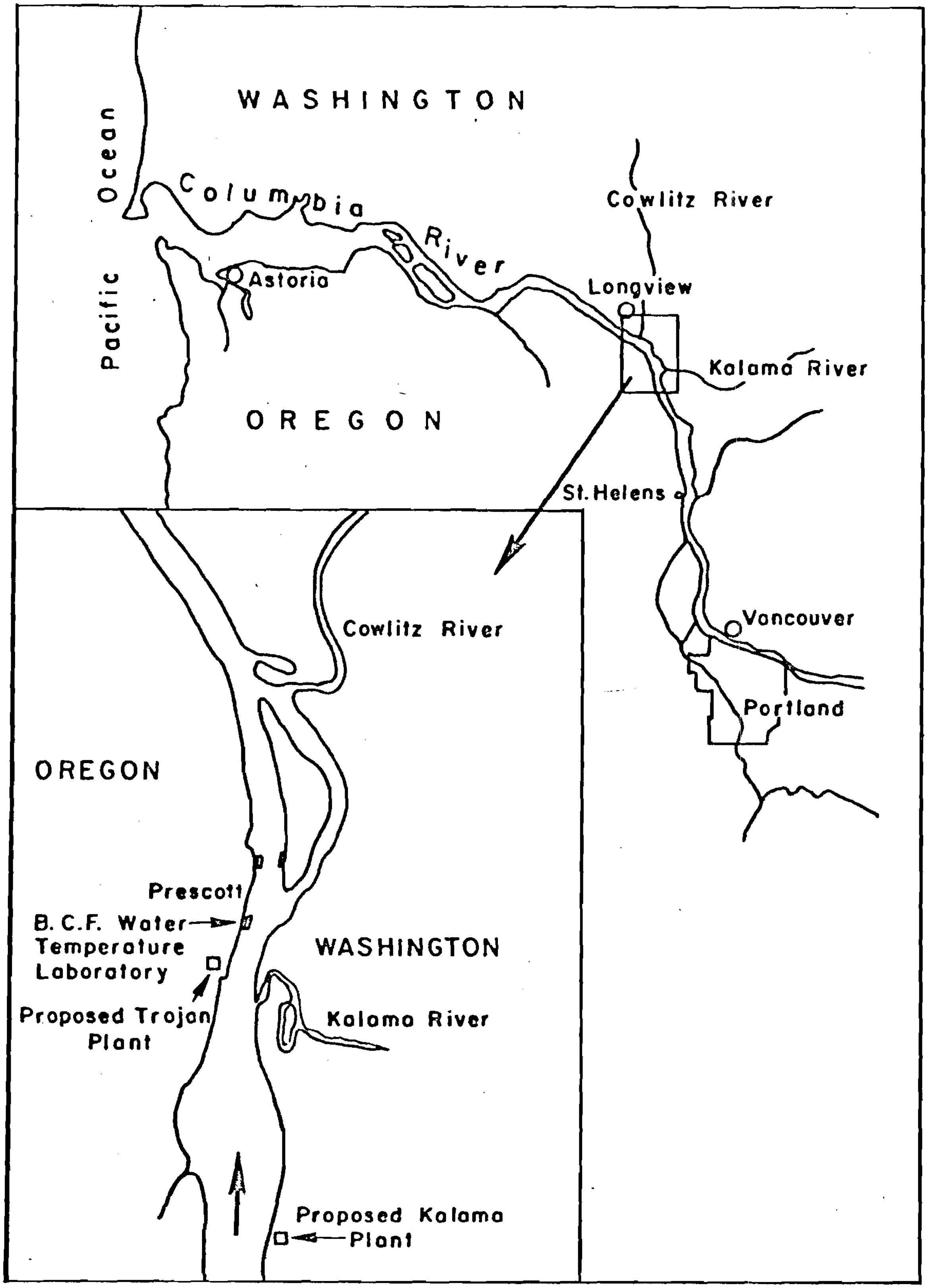


Figure 1.--Water temperature laboratory on the Columbia River at Prescott, Oregon.

Figure 2.--Location of BCF test facility in relation to sites of proposed thermal nuclear power plants.



Oregon. They were transported to the test facility and held pre-test in 1.8 x 2.1 m. redwood tanks through which Columbia River water was circulated at a rate to provide at least one complete interchange of water each hour. Pre-test mortalities were less than 1%. A compilation of fish origin and acquisition date is shown in table 1.

THERMAL SHOCK TEST PROCEDURE

Samples of 20 test fish (with the exception of one test series in which 16 fish were used per sample) were exposed to pre-adjusted test water temperatures, and time to death was recorded. Two observers recorded death times with an electric timer and a stop watch. Physical characteristics of the death process were noted and recorded during each test. Movies were taken to provide a permanent record of thermal shock responses.

A chronological listing of the tests and the water temperatures at which they were conducted is given in table 2.

VARIABILITY IN TIME TO DEATH

Juvenile salmonids exhibit wide variability in response to sharp temperature increases. For example, chinook salmon exposed to 27 C (a 9 C rise above acclimation) incurred mortalities from 4 (first death) to 121 (100% death) minutes (fig. 3). Because of this variability researchers have chosen the point at which 50 percent of the sample dies (LD50) to represent the "upper incipient lethal level" of the specific organism. However, this level should be expressed in terms of time as well as temperature.

Table 1.--Acquisition date and origin of fish used for thermal shock tests

Species	Acquisition date	Origin
Steelhead	4-1-69	Big Creek Hatchery - Oregon
Coho	4-24-68	Columbia River - Prescott, Oregon
"	4-26-68	Kalama Falls Hatchery - Washington
"	3-28-69	" " "
"	5-8-69	Columbia River - Prescott, Oregon
Chum	5-13-68	Hoodsport Hatchery - Washington
"	4-7-69	Big Creek Hatchery - Oregon
Sockeye	10-2-68	Leavenworth Hatchery - Washington
Chinook	3-15-68	Columbia River - Prescott, Oregon
"	9-23-68	" " " "
"	10-24-68	" " " "
"	1-29-69	Brown Bear - Seattle, Washington
"	4-21-69	Columbia River - Prescott, Oregon
"	4-30-69	" " " "
"	6-16-69	" " " "
"	10-27-69	" " " "
Fall chinook	8-13-69	Little White Salmon Hatchery-Washingtc
Spring chinook	8-21-69	" " " " "

Table 2.--Chronological ranking by species and water temperatures of thermal shock tests

Species	Test date	Control temperature (°C)	Test temperature (°C) 26	27	28	29	30
Chum	5-28-68	15		X		X	
Chum	2-27-69	4	X			X	
Steelhead	5-6-69	10	X			X	
Steelhead	5-28-69	14	X			X	
Coho	4-29-68	12			X		
Coho	5-8-68	12	X		X		
Coho	4-22-69	10	X			X	
Coho	6-2-69	14	X			X	
Sockeye	10-8-68	10	X			X	
Sockeye	11-19-68	15	X			X	
Sockeye	7-10-69	10	X			X	
Sockeye	7-24-69	20	X			X	
Sockeye	10-7-69	17	X			X	
Sockeye	10-7-69	12	X			X	
Chinook	4-23-68	10	X			X	
Chinook	9-25-68	17	X			X	
Chinook	2-11-69	4	X			X	
Chinook	4-24-69	10	X			X	
Chinook	5-8-69	10	X			X	
Chinook	6-18-69	18	X	X	X	X	X
Chinook	8-19-69	11	X			X	
Chinook	8-19-69	20	X			X	
Chinook	8-21-69	11	X			X	
Chinook	8-21-69	20	X			X	
Chinook	8-31-69	12	X			X	

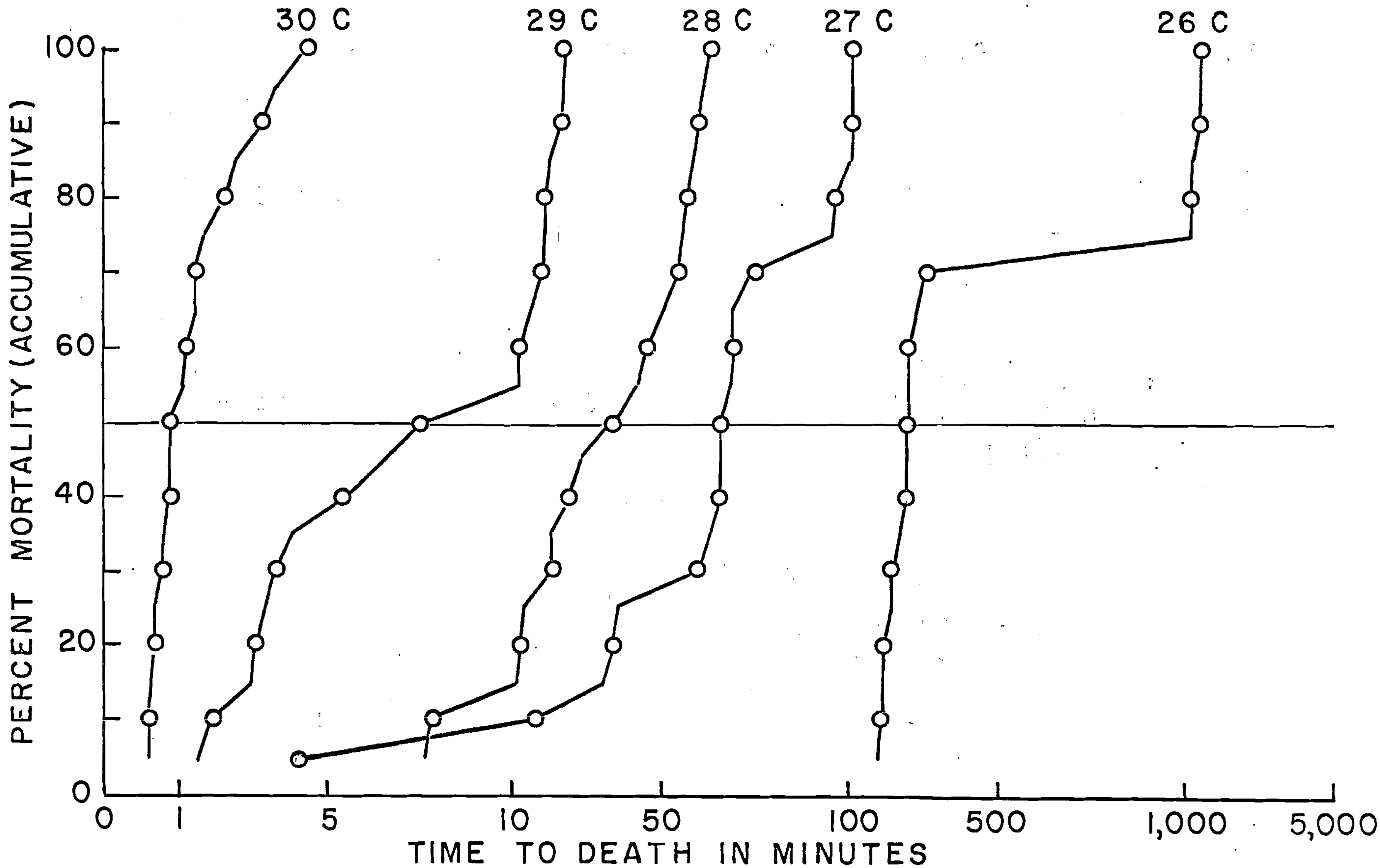


Figure 3.--Time to death and percent mortality of juvenile chinook salmon subjected to sudden temperature increases from 18 C (control temperature).

RESPONSE TO 26 C

First death occurred in all tests at 26 C in less than 120 minutes; control temperatures varied from 4 to 20 C (fig. 4). However, in 17 of the 23 tests at 26 C, the first death occurred in less than 40 minutes.

Twenty-two of 24 tests showed that 50 percent mortality occurred in less than 120 minutes at the 26 C (fig. 4). All fish died in less than 4.5 hours. Generally, higher acclimation temperatures produced longer resistance times.

Replicates of thermal shock tests showed that at 26 C test temperatures, the death process could be reversed. One-hundred percent recovery occurred within 24 hours if the fish were returned to the control temperature as soon as loss of equilibrium was apparent.

RESPONSE TO 29 C

Twenty-five tests were conducted in which juvenile salmonids were subjected to 29 C following acclimation ranging from 4 - 20 C. First death in all tests occurred in less than 2.5 minutes (fig. 5).

Fifty percent mortality was reached in all tests in less than 8 minutes, and in 19 tests in less than 3 minutes. All fish succumbed at 29 C in less than 25 minutes; in 22 of the 25 tests, 100 percent died in less than 10 minutes. Fish acclimated to 18 C displayed a longer resistance to an 11 C increase than did fish acclimated to 20 C and subjected to a 9 C increase.

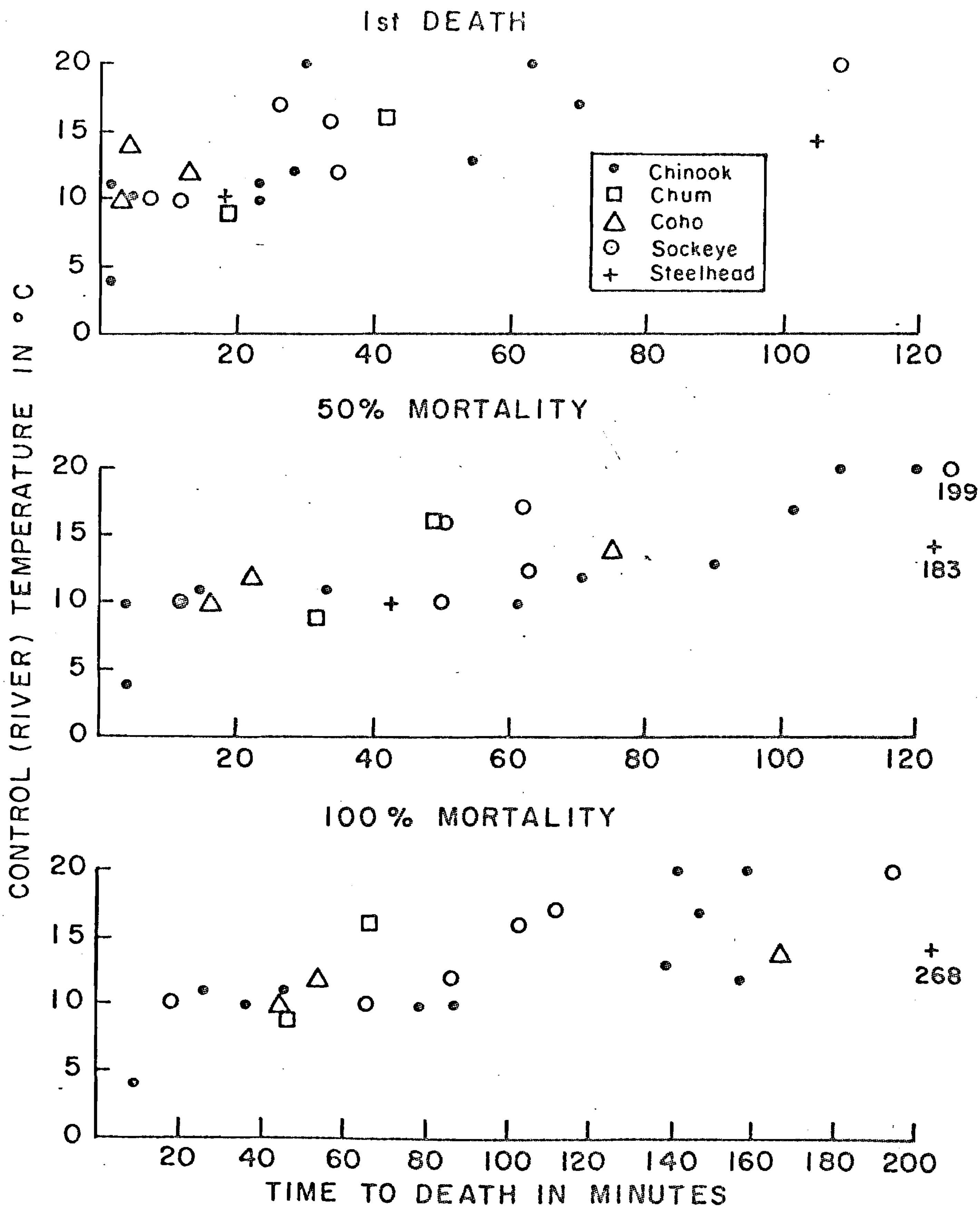


Figure 4.--Mortality of juvenile salmonids subjected to 26° C from designated control temperatures.

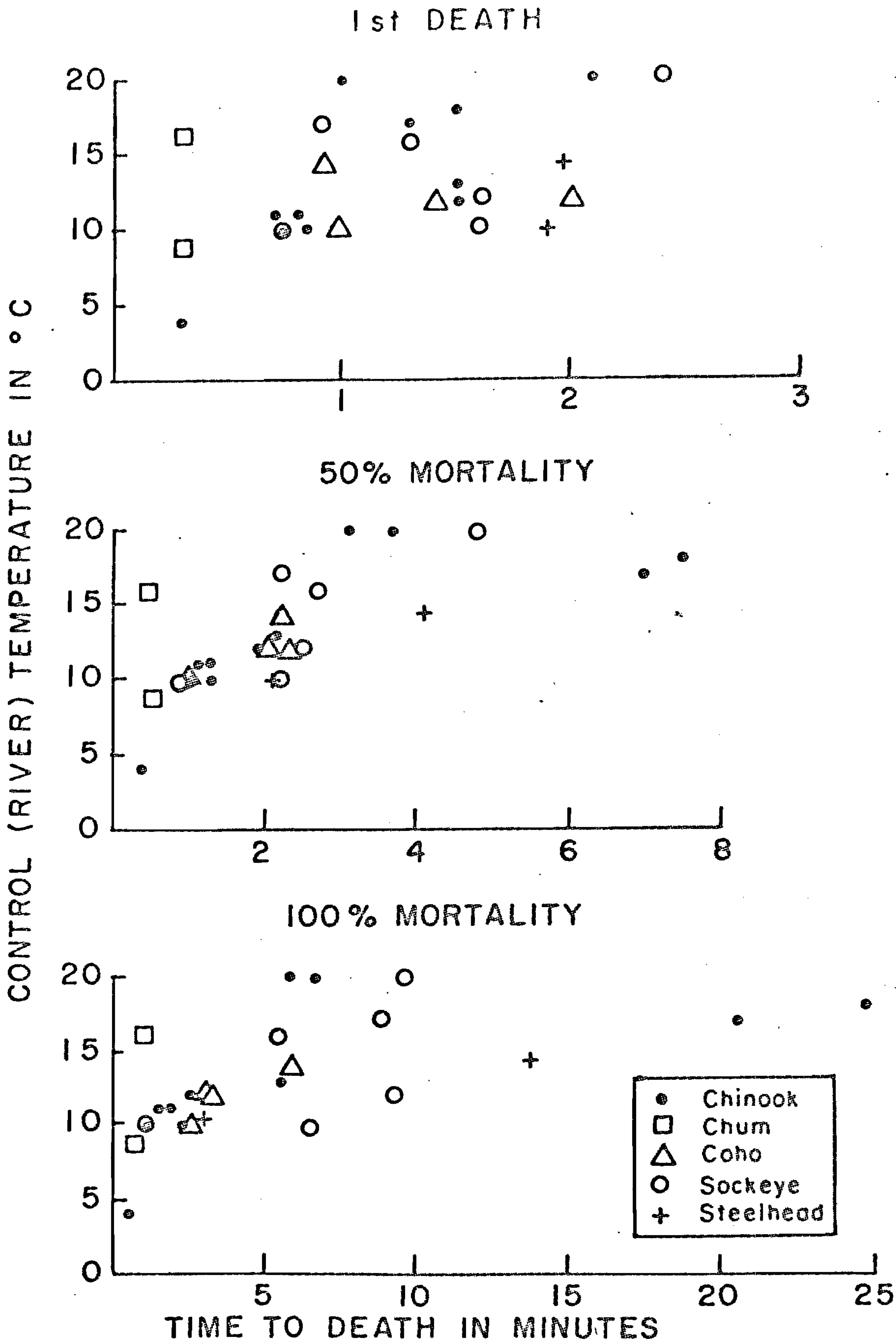


Figure 5.--Mortality of juvenile salmonids subjected to 29° C from designated control temperatures.

At 29 C (and above), loss of equilibrium was seldom prolonged; generally, immediate tetany occurred and the fish would die within minutes. No recovery occurred when stressed fish were immediately returned to the control water temperature.

Fish subjected to 29 C exhibited a violent reaction when placed into the test tank. Movie films show that the erratic (and violent) swimming actions were apparently non-directional and in some instances seemed to be muscle spasms prior to tetany. It is doubtful that a fish involuntarily entering a heated effluent, with water temperatures in the 29 C range, could volitionally escape.

APPLICATION TO EXISTING RIVER CONDITIONS

Mihursky and Kennedy (1967) noted that thermal shock occurred when no acclimation time is possible due to an abrupt change in the thermal environment. Coutant (1970) utilized water temperatures of 26 C and above to thermally "shock" juvenile salmonids. Thermal shock as used in our report was identifiable as an obvious physical response characterized by: (1) at 26 C, progressively increasing activity followed by a gradual loss of equilibrium and subsequent cessation of respiratory action and (2) at 29 C and above, immediate tetany and cessation of respiratory movements. Results of the 26 and 29 C shock tests could have application in the Columbia River where it is possible that such temperatures can occur within the outfall of a thermal discharge for varying periods of time depending on river flows and ambient temperature. For example, the first death in 23 separate tests occurred in less than 2 hours at 26 C, and less than 2.5

minutes at 29 C. Death is so rapid at 29 C that it is doubtful if juvenile fish could escape from the danger area. Furthermore, a sublethal time exposure causing loss of equilibrium could affect the chances of fish to survive in the natural environment. For example, Coutant (1969b) stated that "when a fish exhibits abnormal behavior from thermal shock it is ecologically dead through predation." Water temperatures in the range of 26 to 30 C would, of course, be intolerable in the Columbia River at a point below which thermal discharges are thoroughly mixed with the river flow. As previously noted, however, such temperatures are possible within thermal plumes. Persistence of these lethal temperatures and the extent of fish loss that could occur within a plume will depend on physical characteristics of the river and the ΔT and volume of the thermal discharge. Obviously, if off-river cooling facilities are applied, far greater protection would be afforded the fish due to reduced volume and area of the thermal plume and persistence of lethal temperatures within the area of discharge. We, therefore, believe that characteristics of thermal plumes and their potential effects on aquatic biota should be among the factors considered in establishing water quality standards for the Columbia River.