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WESTERN PROCEEDINGS

Fiftieth Annual Conference

of the

WESTERN ASSOCIATION OF STATE GAME AND FISH COMMISSIONERS

VICTORIA, BRITISH COLUMBIA

July 13-18, 1970

P R O C E E D I N G S

of the

FIFTIETH ANNUAL CONFERENCE

of

WESTERN ASSOCIATION OF STATE GAME AND FISH COMMISSIONERS

Victoria, British Columbia

July 13-16, 1970

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THERMAL EFFECTS STUDIES ON THE LOWER COLUMBIA RIVER; 1968-70

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INTRODUCTION

In 1967, the Bureau of Commercial Fisheries (Prediction of Environment Program, Biological Laboratory, Seattle, Washington) initiated "on-site" studies to assess the potential impact of proposed thermal electric plants on the aquatic environment of the lower Columbia River. Initial work was to be concerned with the limnology of the study area near the sites of two proposed plants (fig. 1) and the effect of thermal increases on indigenous species of fish.

When water temperature standards for Oregon and Washington were submitted to the Department of the Interior for review early in 1968, certain discrepancies were noted between standards of the two states for interstate waters of the lower Columbia River. Subsequently the Secretary of the Department of the Interior directed a study to define the effects of water temperature increases on aquatic organisms in the Columbia River. Information gained from this research would be expected to form the basis for a uniform set of water temperature standards applicable to interstate waters of the region. The lead agency designated for this study was the Federal Water Pollution Control Administration (now Federal Water Quality Administration). The FWQA formed a Technical Advisory Committee of industrial and resource protection representatives to evaluate the research needs and objectives of this study. The FWQA then enlisted the assistance of the Atomic Energy Commission and the Bureau of Commercial Fisheries to conduct research recommended by the Technical Advisory Committee. The FWQA requested that the Bureau accelerate "on-going" studies and provided partial funding for the research.

Research by the Bureau of Commercial Fisheries was programmed into seven projects that relate directly or indirectly to the effects of increased temperature on the aquatic biota of the Columbia River. This summary report covers results of the following projects:

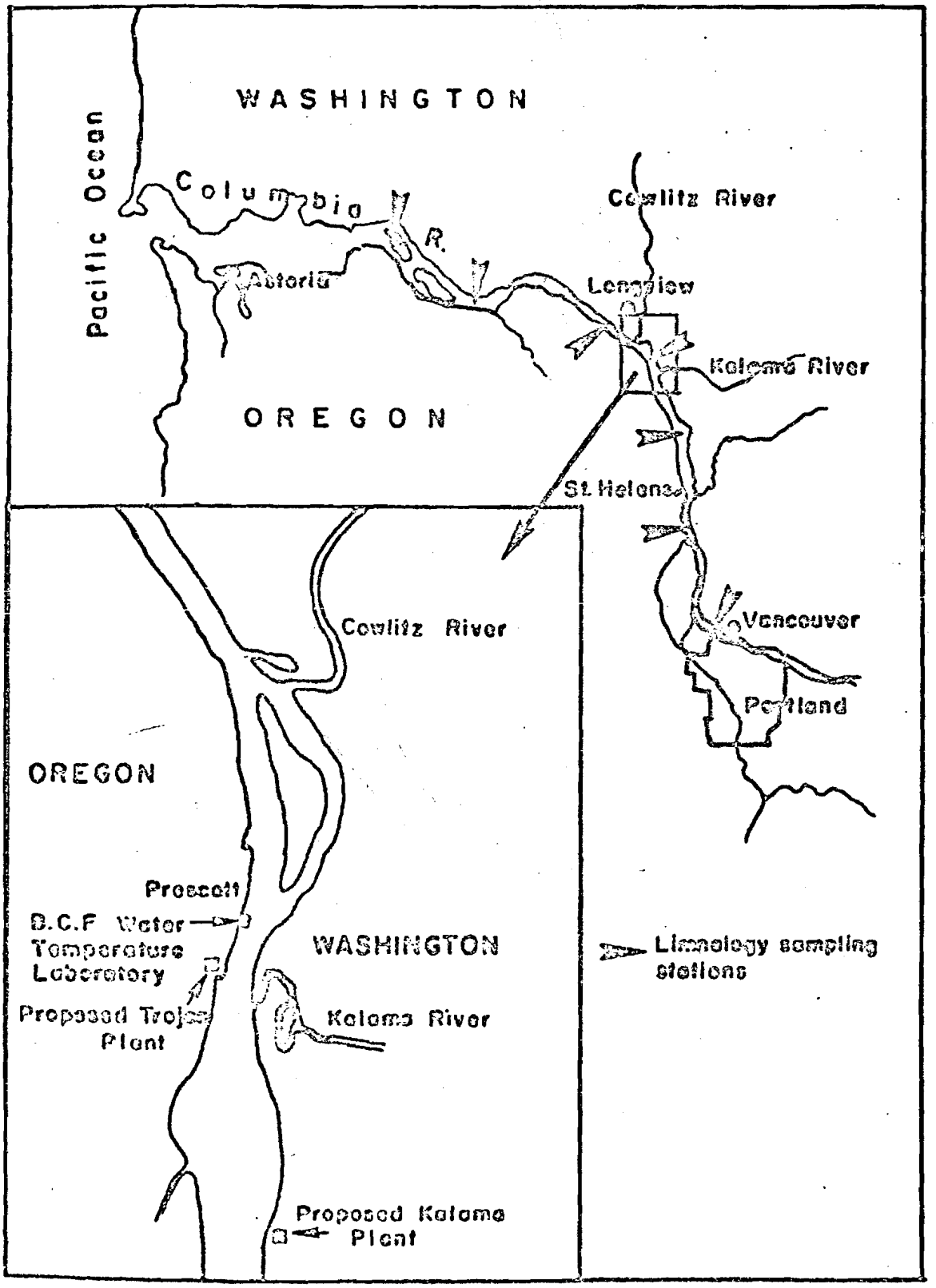
(1) Limnological survey of the lower Columbia River

(2) Time of migration and occurrence of fish near Prescott, Oregon

(3) Thermal tolerance of juvenile salmon and trout

(4) Thermal tolerance of non-salmonids

Figure 1.—Study area for thermal effects research conducted by the Bureau of Commercial Fisheries.



(5) Effect of thermal shock on juvenile salmon and trout

(6) Effect of N_2 supersaturation on fish in the lower Columbia River

(7) Abundance, utilization by fish, and thermal tolerance of zooplankton

The purpose of this report is to summarize the results of 2 years of research.

THE TEST FACILITY

In 1967, a floating laboratory (Snyder, Blahm, and McConnell, 1970) was established on the Columbia River at Prescott, Oregon, to pursue environmental studies and research on fish and other organisms subjected to thermal stress. The site was selected to examine the physical, chemical, and biological features of the river before proposed thermal electric plants are installed. In addition, "wild" and "hatchery" fish could be taken directly from the river and be held and exposed to temperature increases in river water.

The laboratory was equipped with biological and chemical laboratories as well as two "wet" laboratories containing a total of forty-four 50-gallon tanks. Quality of the river water could be monitored, and the water could be heated or cooled for temperature experiments. The laboratory also served as a base for crews employed in limnological and biological surveys (fig. 2).

LIMNOLOGICAL SURVEYS

The following is a summation of results from the physical, chemical, and biological surveys conducted at the Prescott site throughout the study. More complete and detailed compilations of data are included in the various reports cited.

Temperature

Water temperature of the lower Columbia River ranges from highs of 24 C during August to lows of 1.3 C during January. Diel fluctuation approximates 1 C throughout the year (Snyder and McConnell, 1970). Annual temperature patterns are typical of regulated rivers, i.e., gradual increases and decreases that form smooth, bell-shaped distributions with no abrupt changes. A comparison with earlier surveys shows a general upward trend in water temperature (previously noted by Moore, 1968).

Figure 2.--Floating water temperature laboratory, Columbia River at Prescott, Oreg.

Flow

Average daily flow of the Columbia River at Prescott, Oregon, varied from a low of 78,603 cubic feet per second (c.f.s.) during August 1969, to a high of 501,000 c.f.s. during May 1970 (U.S. Geological Survey, 1970). Velocity and direction of flow were constantly monitored during the study, and negative or upstream flow was common. A flow reversal study, using Rhodamine-B dye as a mass water tracer, revealed that reversals could be extensive at low river flows and high oceanic tides; during a 4-hour period water moved more than 3 miles upstream. The reversal study indicated that the effect of heated discharges from thermal electric plants could more than triple (3.5 times) during reversal as compared to unrestricted downstream flow (Clark and Snyder, 1970a). Examination of river flow and tide records indicate that reversals are predictable.

Chemical analysis

Limnological data were collected at seven sampling stations from above the mouth of the Willamette River to below Puget Island. Variables monitored were pH, dissolved oxygen, phosphate, silicate, calcium, magnesium, and sodium. A complete and specific analysis of these variables was made by Clark and Snyder (1970b). A comparison with earlier surveys indicates a downward trend in dissolved oxygen levels.

Biological

Chlorophyll a and zooplankton were sampled periodically at seven stations from the Willamette River to below Puget Island. Chlorophyll a abundance peaked in April-May and again in September-October. Zooplankton abundance peaked in September, remained low through the winter, and slowly increased in early spring (Clark and Snyder, 1970b).

TIME OF MIGRATION AND OCCURRENCE OF FISH

Sampling sites (fig. 3) were established above and below Prescott to survey the distribution and abundance of fish in the river throughout the year. Fish were captured with purse and beach seines, and the numbers of various species in the catches were recorded. In addition, data were taken on the occurrence of juvenile salmon and trout in relation to the proposed thermal plant sites. Major emphasis was given to the collection of juvenile Pacific salmon and trout because they are particularly vulnerable to temperature changes during their downstream migration to the ocean.

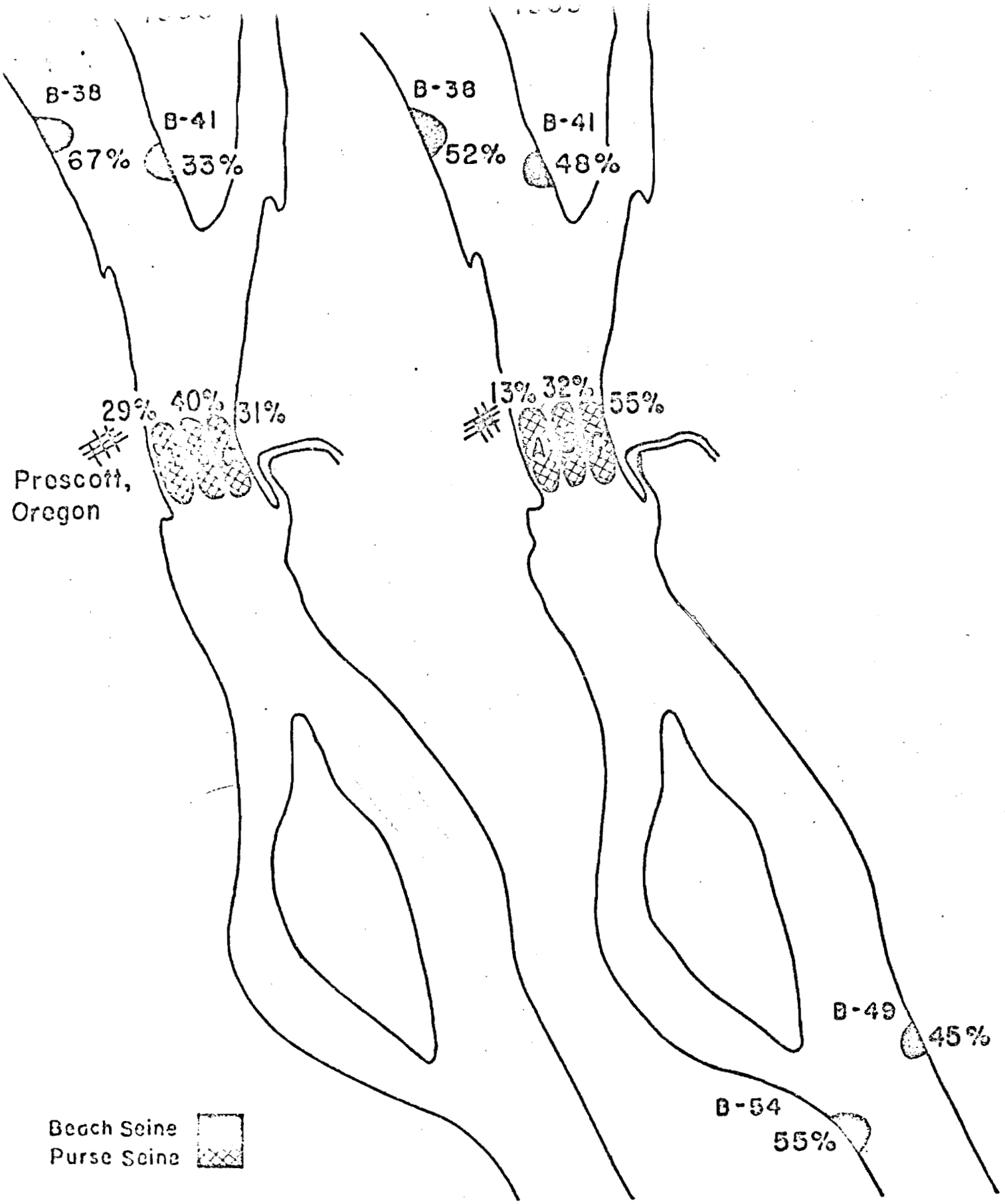


Figure 3.--Percent occurrence of juvenile salmonids at the sampling sites during 1968-69.

The object of the sampling was to ascertain periods of peak migrations and to determine the relative abundance of different species of fish during all months of the year. Such information is necessary because temperature increases and the time of their occurrence in the river would be more critical to some species than to others.

Time of migration of juvenile salmon and trout

Salmon and trout were taken in samples every month in 1968-69 (fig. 4), but the peak abundance was in May. Juvenile chinook salmon (26,532 fish) were dominant, comprising 80 percent of the total catches (31,477 fish) of salmon and trout (McConnell and Snyder, MS 1970). The peak of the chinook outmigration occurred in June in 1968 and in May in 1969. The peaks of abundance of other salmon and trout were similar as shown in figure 4.

Marking experiments showed that some migrating juvenile salmon move slowly or remain in the lower river over long periods. Downstream passage from Bonneville Dam to Prescott takes 1 to 10 days, depending on the velocity and volume of river flow. Catch data indicate that some Cowlitz River fish (spring and fall chinook juveniles) remain in the lower Columbia River for as long as 6 months. Fish released from the Cowlitz River Hatchery in September 1969 were recaptured from October 1969 through April 1970 upstream from the confluence of the Cowlitz and Columbia Rivers.

Time of movement of other species of fish

Twenty-one species of fish other than salmon and trout were captured (fig. 5). Some species were present the entire year, but others were captured in only one month. Peak abundance of more than half of the species was in the May-July period. Anadromous species included adult eulachon and juvenile American shad that had migration peaks in February and October respectively.

Distribution of juvenile salmon and trout

The distribution of juvenile salmon and trout was sampled to determine whether the fish preferred specific portions of the river in their migrations. Preference of the fish for one side or for the middle of the river would be a factor to be considered in the operation of thermal electric plants.

The distribution of the fish sampled at Prescott, Oregon, in 1968-69 is shown in figure 3. During 1968, purse seine catches showed the fish were distributed relatively uniformly across the river, but in 1969 more fish were caught along the Washington side. Higher flows and turbidity during the 1968 outmigration may have influenced the results that year.

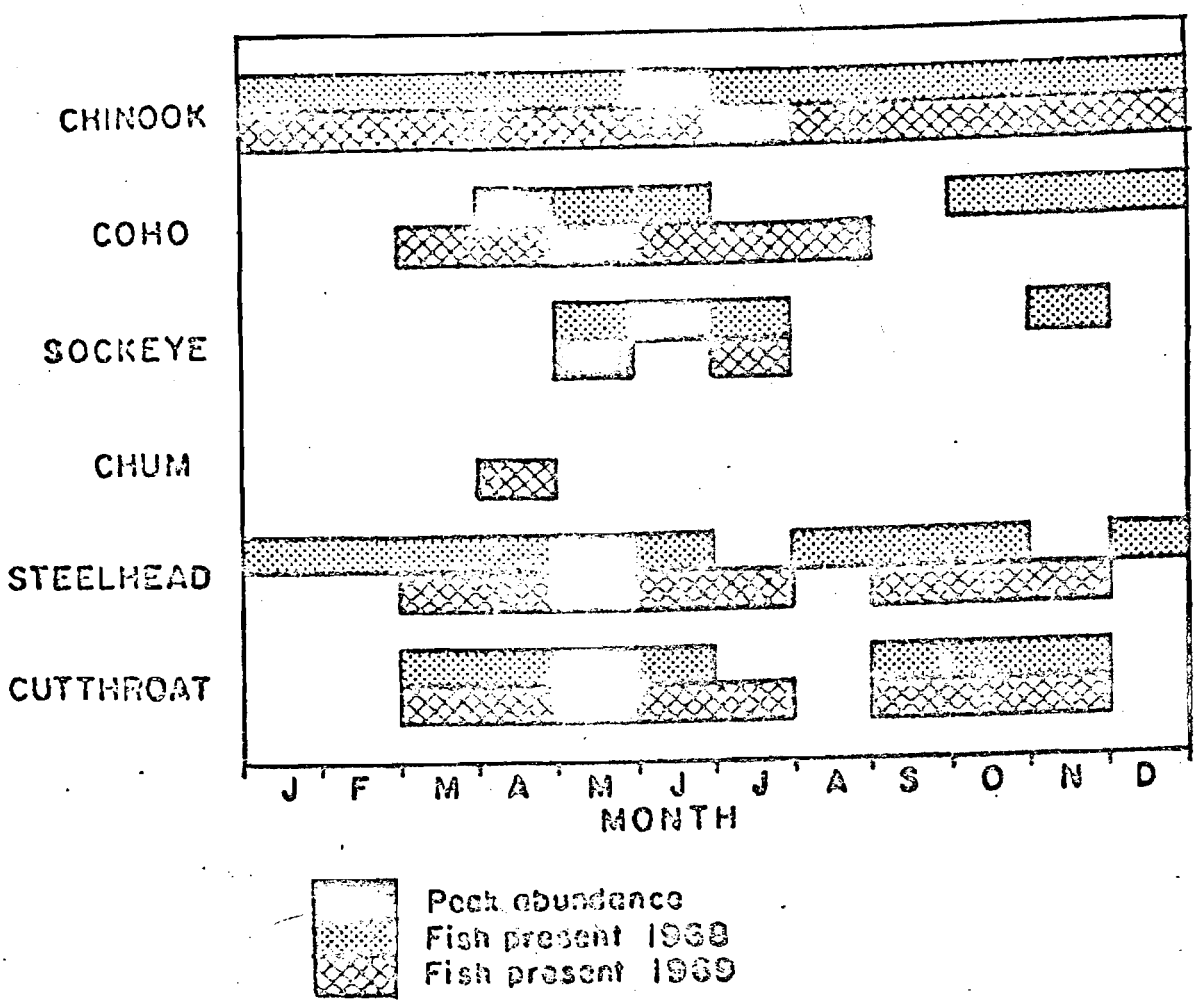


Figure 4.--Monthly and total catches of downstream migrant salmon and trout at Prescott, Oregon, 1968-69.

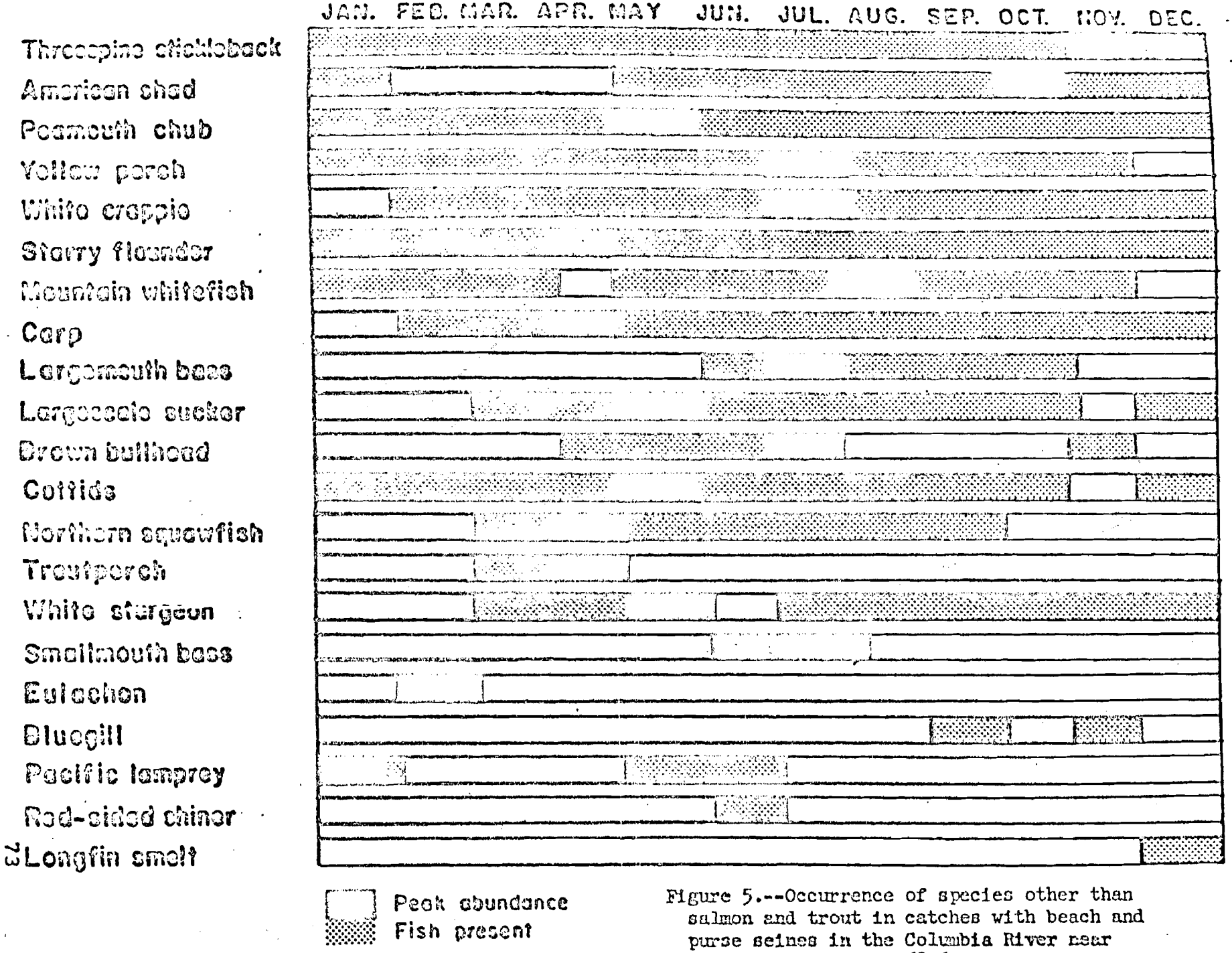


Figure 5.--Occurrence of species other than salmon and trout in catches with beach and purse seines in the Columbia River near Prescott, Oregon, 1968-69.

THERMAL TOLERANCE OF FISH

The objective of thermal tolerance experiments was to define the effect of temperature increases on the fish found in the study area. The effects of short-term and long-term exposure to elevated temperatures were tested.

Thermal tolerance of juvenile salmon and steelhead trout

Four species of salmon (chinook, chum, coho, and sockeye) and 2 species of trout (cutthroat and steelhead) are in the lower river. Thermal tolerance tests were conducted on the 4 species of salmon in 1968 and 1969 at the Prescott laboratory. Steelhead trout also were tested in 1969.

1968 tests.--Test temperatures were established (using ambient river temperature as a base) above and below the 20 C (68 F) suggested maximum water temperature standard. Eight tests were conducted during 1968. These preliminary tests were designed to establish the effects of exposure of the fish to elevated water temperatures (fig. 6) for various periods of from 1 hour to 2 weeks. Results were as follows:

(1) With chinook salmon acclimated to 10 C, a 37-minute exposure to 26.7 C (16.7 rise) caused 100% mortality; acclimated to 17 C and 8 C increase would result in a 50% mortality in 102 minutes.

(2) With chum salmon acclimated at 15.6 C, a 50% mortality occurred at 26.7 C; however, these tests did not establish true lethal levels because of the transitory exposure (1-hour) to the elevated temperatures.

(3) The first mortality of juvenile coho was recorded at 26 C in 13 minutes; 50% and 100% mortality at 26 C were 22.5 and 52 minutes respectively.

(4) Sockeye juveniles acclimated to 15.5 C reached a 50% mortality at 20 C in 11,455 minutes.

1969 tests.--Eighteen tests were completed during 1969 and are summarized in figure 7. All fish were exposed to test temperatures for a maximum of two weeks. Results were as follows:

(1) Sockeye salmon (6 tests) reached a 50% mortality at 22 C and 100% at 24.5 C. Nitrogen gas and disease were major problems (McConnell and Blahm, MS 1970).

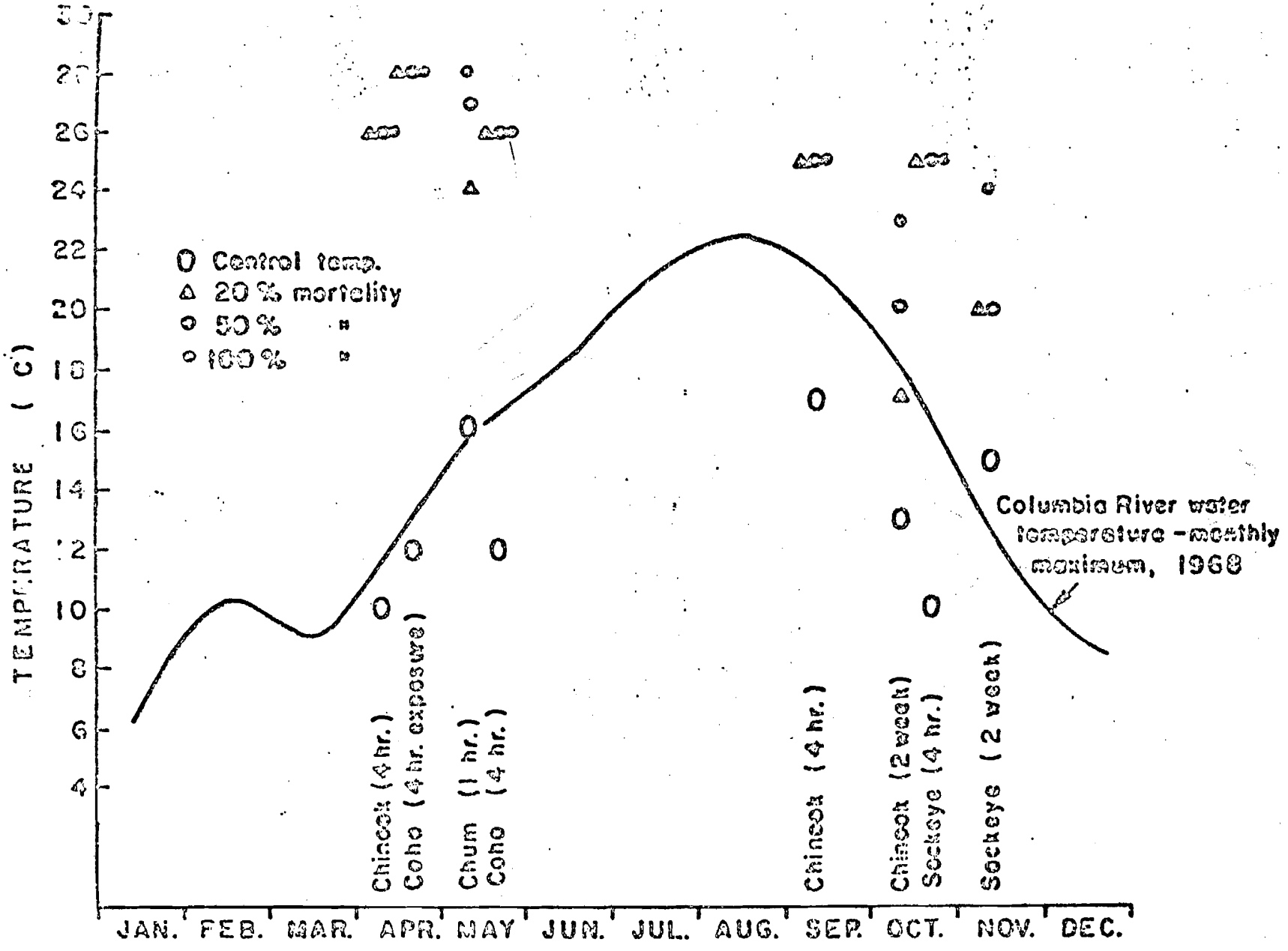


Figure 6.--Summary of thermal tolerance tests on juvenile salmon, 1968.

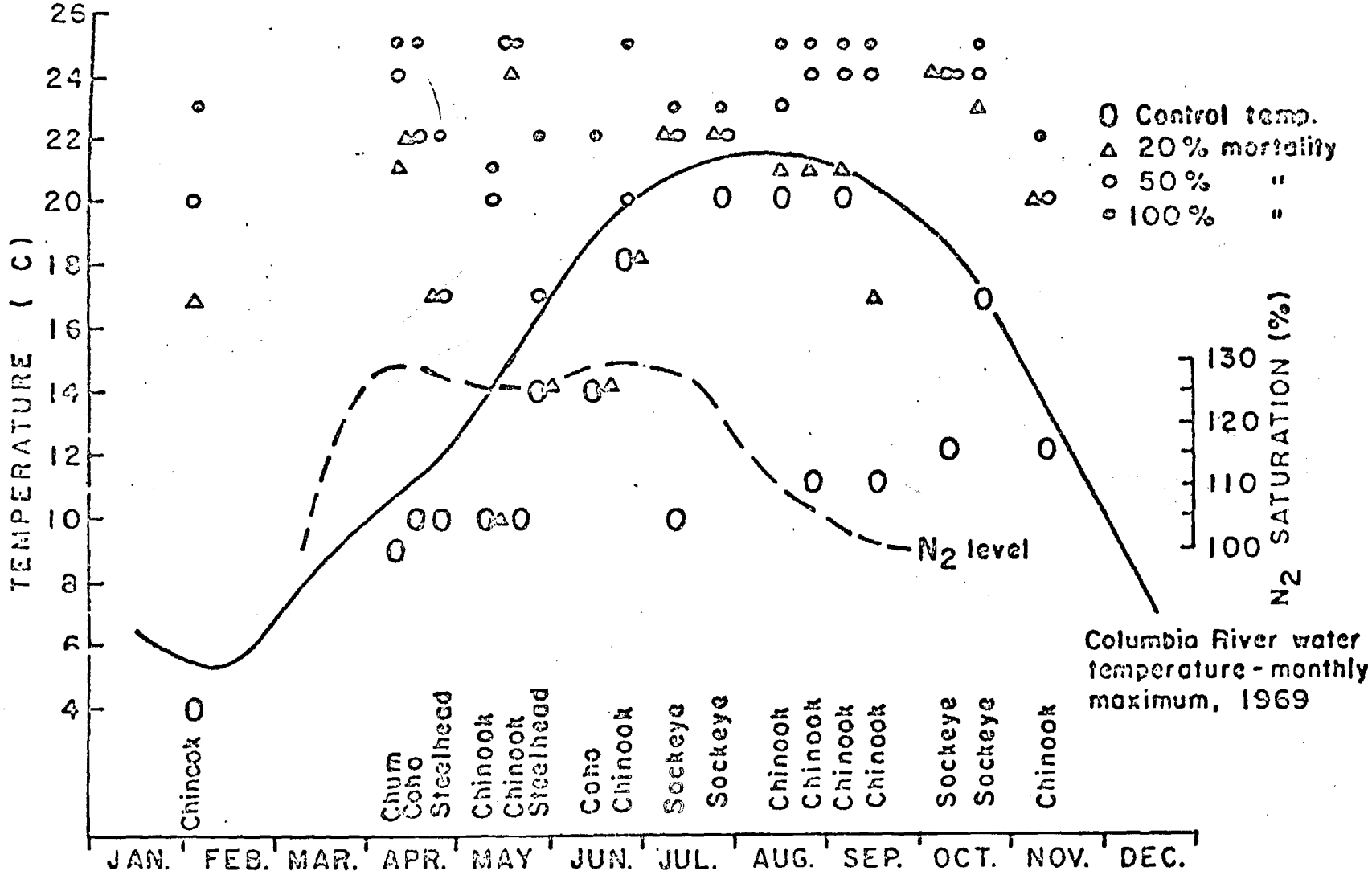


Figure 7.--Summary of thermal tolerance tests on juvenile salmon and steelhead trout at the BCF laboratory, Prescott, Oregon, 1969.

(2) Lethal levels for chinook salmon (12 tests) were at least 4 C below previously published data, with one exception (Blahm and McConnell, MS 1970a; Snyder and Blahm, MS 1970a).

(3) Steelhead trout (2 tests) appear to be the least resistant to temperature increases--with fish acclimated to 10 and 14 C a 50% mortality was reached at 17 C and 100% mortality at 22 C; nitrogen gas was high during these tests (Snyder and Craddock, MS 1970).

(4) Chum salmon (2 tests) mortalities were recorded at 20 C and above. The lethal level (24 C) was reached more rapidly than expected (Blahm and Parente, MS 1970b); a 50% mortality of 276 minutes was recorded at 24 C at the Prescott Laboratory, whereas, Brett (1952) indicated that a 50% mortality was reached with juvenile chum salmon in 1200 minutes at 24 C.

(5) Coho salmon (4 tests) reached a 50% mortality at 22 C. Excessive mortality was noted in the control groups and thought to be associated with high N_2 saturation in river water. During the test period, a sample of coho captured in the river showed that 31% had symptoms of gas bubble disease (Blahm and McConnell, MS 1970c).

It was concluded that: (1) water quality (other than temperature) played a critical role in these tolerance tests; (2) high N_2 gas saturation probably produced the most important indirect effect with imposed temperature increases; (3) resistance levels were reduced in most cases 3 to 5 C from previously published laboratory findings, and in tests where the lethal temperature level was not reduced, time to death was shortened, and (4) mortalities occurred at test temperatures which were similar to naturally occurring river water temperatures.

Thermal tolerance of non-salmonids

The effects of thermal increases were tested in 1968-69 on four species of non-salmonids: eulachon (Thaleichthys pacificus), yellow perch (Perca flavescens), threespine stickleback (Gasterosteus aculeatus), and white sturgeon (Acipenser transmontanus) (fig. 6).

Eulachon.--Eulachon, or Columbia River smelt, are numerous during December through March. They constitute a valuable sport and commercial fishery and are an important part of the diet of spring chinook salmon and sturgeon. Eulachon eggs appear to be more tolerant than adults to temperature increases; eggs can withstand 14 C increases without appreciable mortality (Parente and Ambrogetti, MS 1970) but a 3 C increase halts maturation of adult females (Bureau of Commercial Fisheries, MS 1970). A 6 C increase for 8 days caused 100% mortality among adults tested. A 50% mortality occurred when eulachon were subjected to an 8 C increase for 1 hour (Blahm and McConnell, MS 1970b).

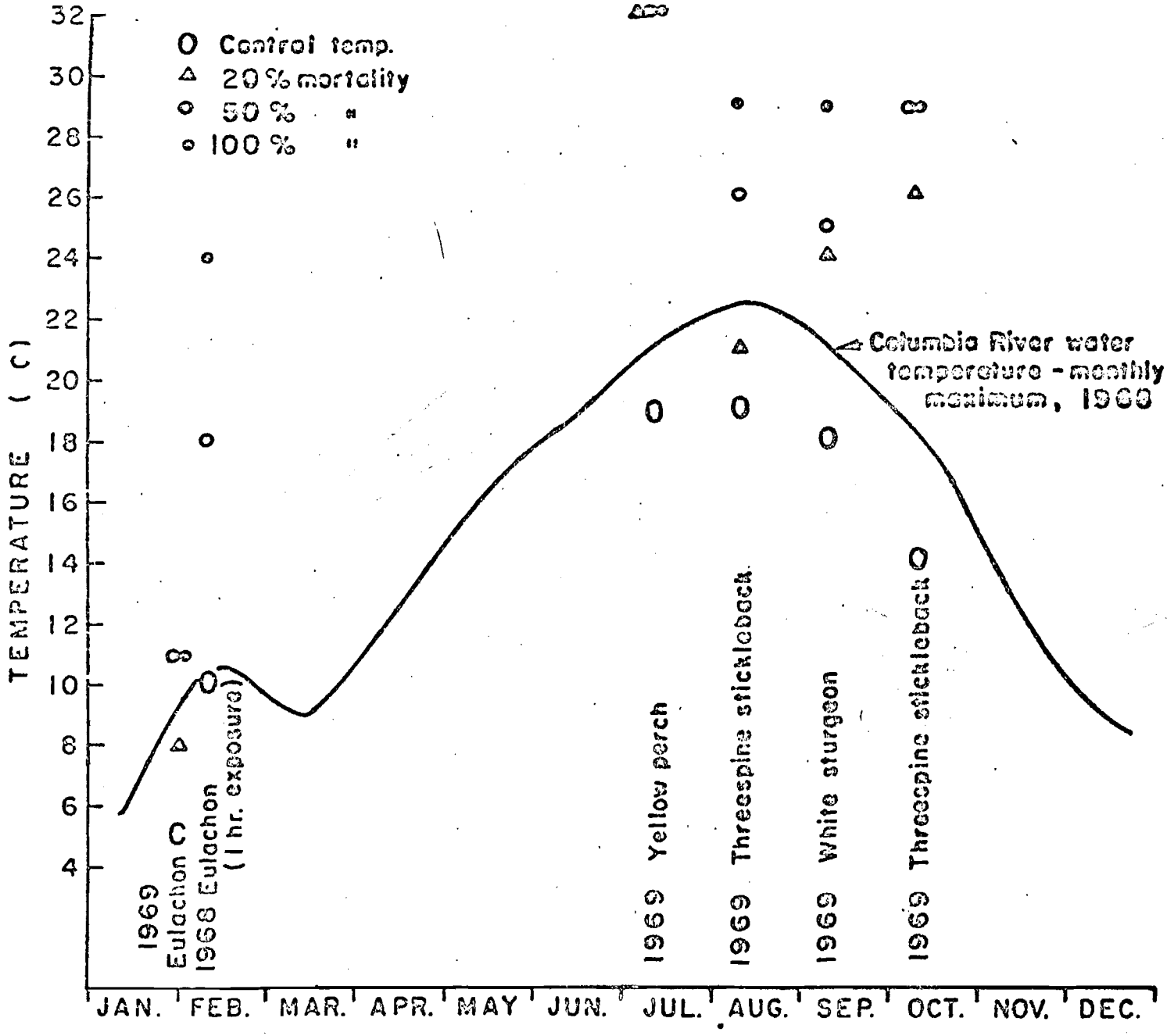


Figure 8.--Summary of thermal tolerance tests on non-salmonids, conducted at the BCF laboratory, Prescott, Oregon, 1968-69.

Yellow perch.--Considered a predator and a competitor in the lower Columbia River, yellow perch tested from control temperature (18 C) to 34 C reached 20, 50, and 100 percent mortality at 32 C (Blahm and Parente, MS 1970a).

Threespine stickleback.--The threespine stickleback, considered a competitor to juvenile salmon in the Columbia River, reached a 50% mortality at 26 C and 100% at 30 C. They appear to be more resistant than salmon to temperature increases (Blahm and Parente, MS 1970a).

Juvenile white sturgeon.--Juvenile white sturgeon exhibited 50% mortality at 25 C and 100% at 29 C.

EFFECT OF THERMAL SHOCK ON JUVENILE SALMON AND TROUT

Tests were conducted to represent the abrupt change of temperature juvenile salmon and steelhead trout could experience moving through a thermal discharge. Four to five hour flow reversals in the lower river may compound the severity of temperature increases. Test temperatures from 26 to 30 C represent temperatures that could be produced by a conventional thermal nuclear plant; these temperatures are 2 to 4 C higher than the average maximum temperature of the lower river. The reactor plumes in the Hanford area are known to produce temperature increases of 17 C (Coutant, 1969) in the Columbia River. In 22 separate tests, 100% mortality of salmon was observed in less than 3 hours at 26 C. A 50% mortality was recorded in less than 2 hours in the same tests with the exception of one sockeye salmon. First death occurred in less than 2 hours in all tests at 26 C (fig. 9). The steelhead had 100% mortality in about $4\frac{1}{2}$ hours.

At 29 C, the first death (in 21 tests of 20 fish each) occurred in less than 2.5 minutes. A 50% mortality was observed within 8 minutes, and 100% mortality occurred in all tests in less than 25 minutes (fig. 10) (Snyder and Blahm, MS 1970b). Individual variation was less evident with juvenile chinook salmon as test temperatures increased from 26 to 30 C (fig. 11).

EFFECT OF NITROGEN SATURATION

High levels of dissolved nitrogen are reached in the Columbia River from March to August, the time of peak migrations of juvenile salmon and steelhead trout. Fish supersaturated with nitrogen have lower tolerance for higher temperature and suffer gas bubble "disease" (Ebel, 1969).

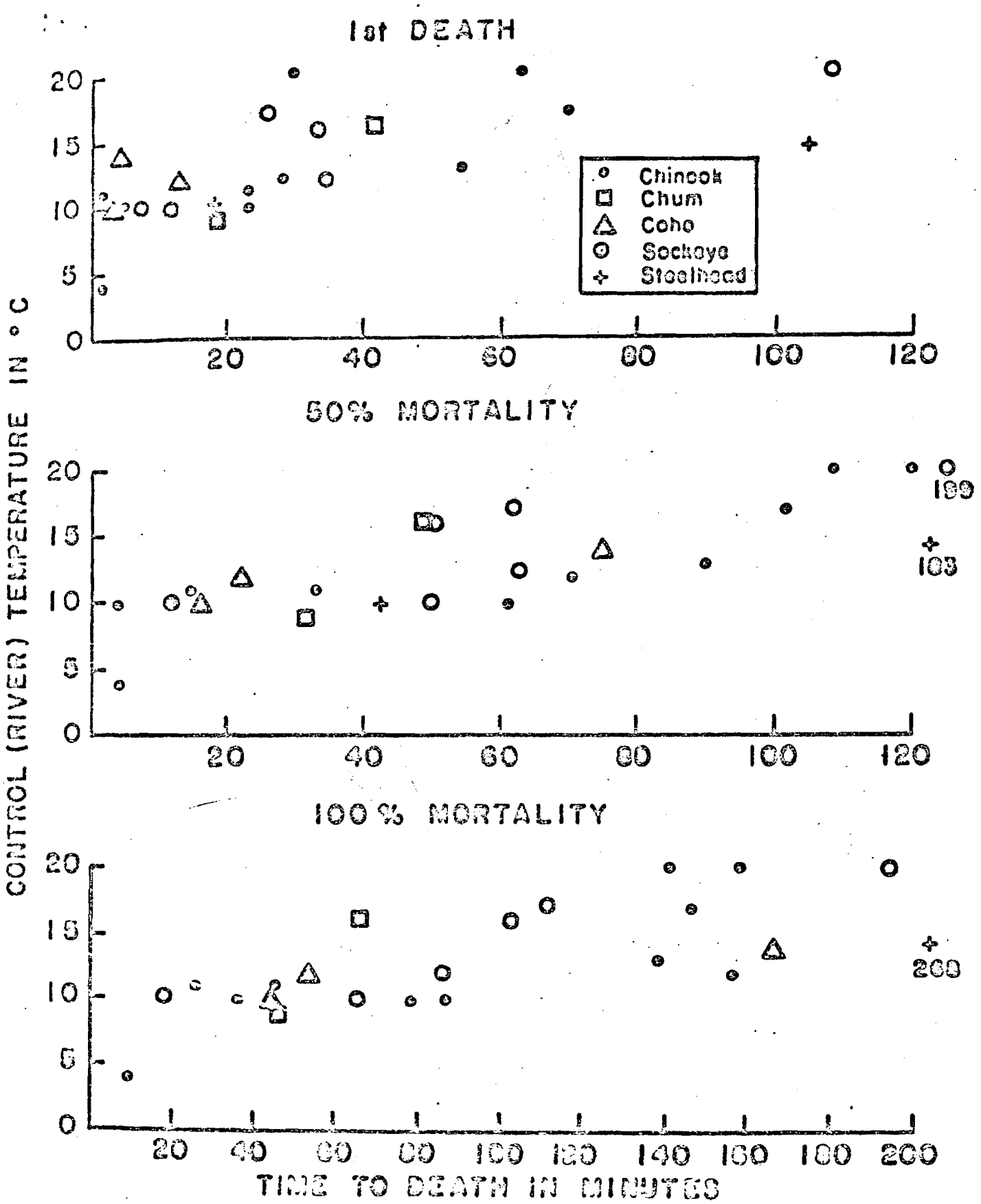


Figure 9.--Mortality of juvenile salmon and steelhead trout subjected to 26 C from designated control temperatures.

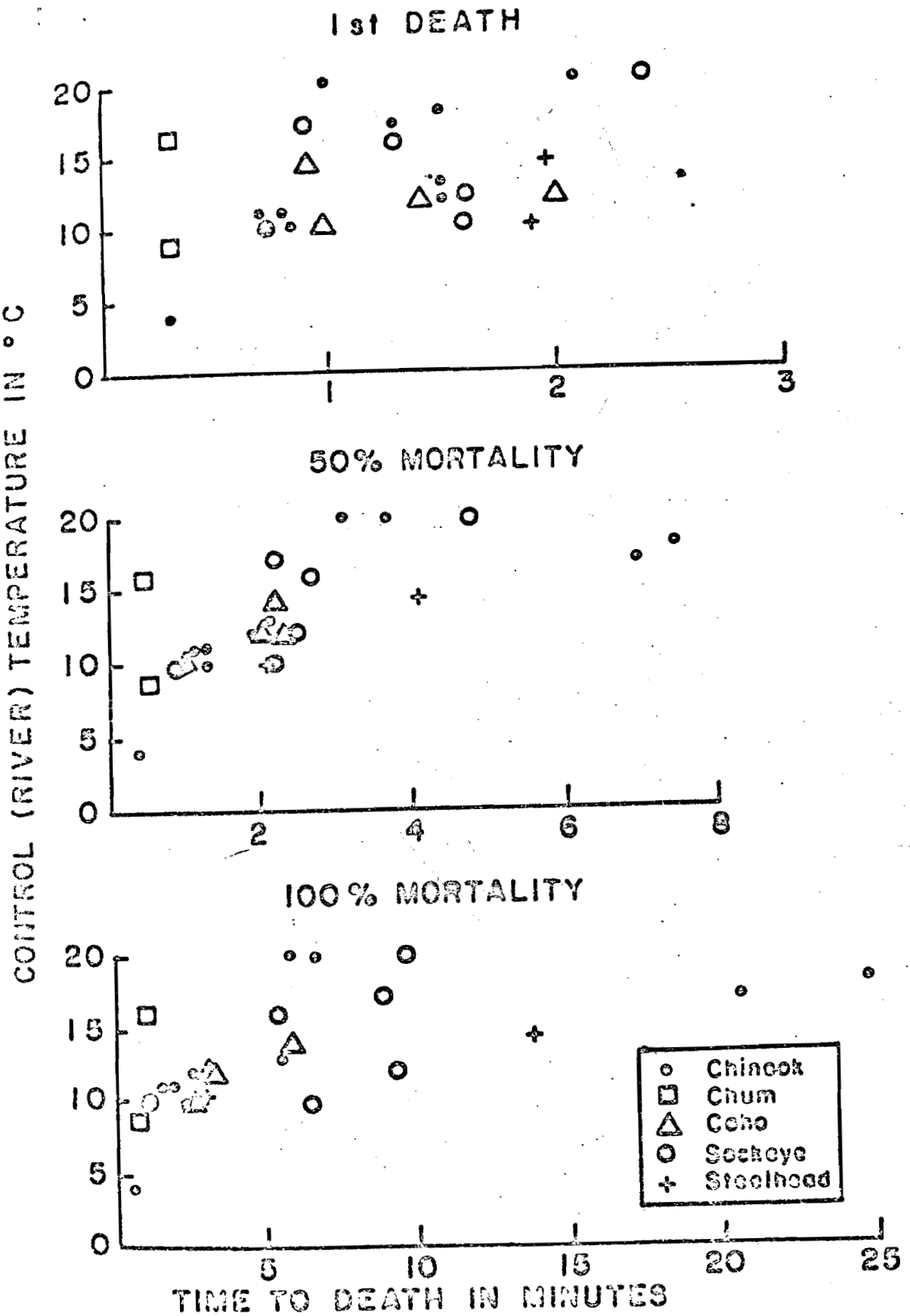


Figure 10.--Mortality of juvenile salmon and steelhead trout subjected to 29 C from designated control temperatures.

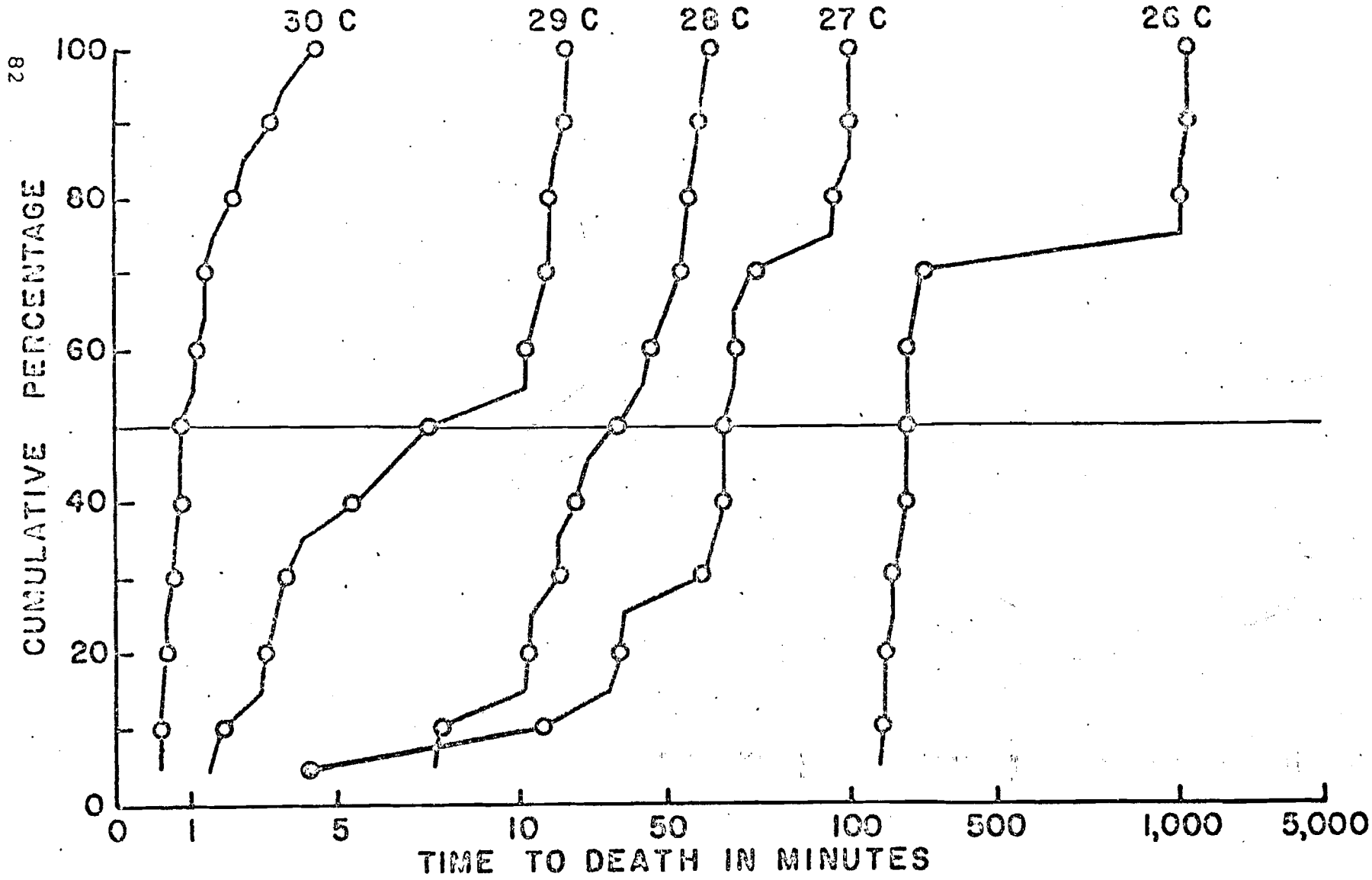


Figure 11.--Time to death and percent mortality of juvenile chinook salmon (20-fish samples) subjected to sudden temperature increases from 18 C (control temperature).

Nitrogen levels in laboratory and river water were comparable. An increase in water temperature in the river results in an increase in the percent of N_2 saturation. When the N_2 saturation was above 110%, the temperature tolerance levels of the fish were lower (fig. 7).

The exact saturation level that produces gas bubble disease has not been established. During April 1969, when N_2 saturations were in the range of 120-130+%, 13 checks were made at beach seine sites during a 3-week period to determine if river fish had symptoms of the "disease". A total of 172 chinook were examined; 22 (12.7%) had symptoms. Of 373 coho juveniles checked, 67 (17.9%) had symptoms. In May one sample of coho showed 31% had symptoms.

Deaths that could be attributed to N_2 disease during thermal tolerance tests were noted. There appeared to be no consistent percentage of affliction (or death) that could be correlated with specific temperature increases. In general, an increasing frequency of nitrogen disease symptoms was associated with increasing temperatures. Fish with gas bubble symptoms were more susceptible to bacterial and fungus infections which resulted in death.

ABUNDANCE, UTILIZATION BY FISH, AND THERMAL TOLERANCE OF ZOOPLANKTON

This study included three concurrent phases: (1) zooplankton abundance in the lower river, (2) the utilization by juvenile chinook salmon, (3) the effect of temperature increases on the most important zooplankter.

Zooplankton abundance was sampled on a regular basis; Daphnia was the most abundant Cladoceran followed by Bosmina. Cyclopoids were the most abundant copepod followed by calanoids. Abundance of zooplankton increased with increasing water temperature (fig. 12) (Craddock and Parente, MS 1970).

Utilization of zooplankton, as a food source, by juvenile chinook salmon was established through stomach sample analysis. Samples were collected during July through October 1968 and March through December 1969. Insects were the major part of the diet in spring and fall months, whereas zooplankton were of major importance from July through October. Over 95% of the zooplankton contents of the stomachs in August-October 1968, and June through December 1969 were Daphnia; juvenile chinook appear to be selective for Daphnia (Craddock and Parente, MS 1970).

Thermal tolerance tests were conducted in the laboratory in Seattle, using Daphnia from the Columbia River (Prescott, Oregon) and from a small pond near Seattle. Maturing and day-old Daphnia pulex (acclimated to 15 C) had 50% mortality in less than 24 hours and 100% mortality in less than 48 hours at 30 C. Higher temperatures reduced survival time. There was no reproduction at 30 C or above. Daphnia that were nearly mature when testing began had decreased reproduction as the temperature increased,

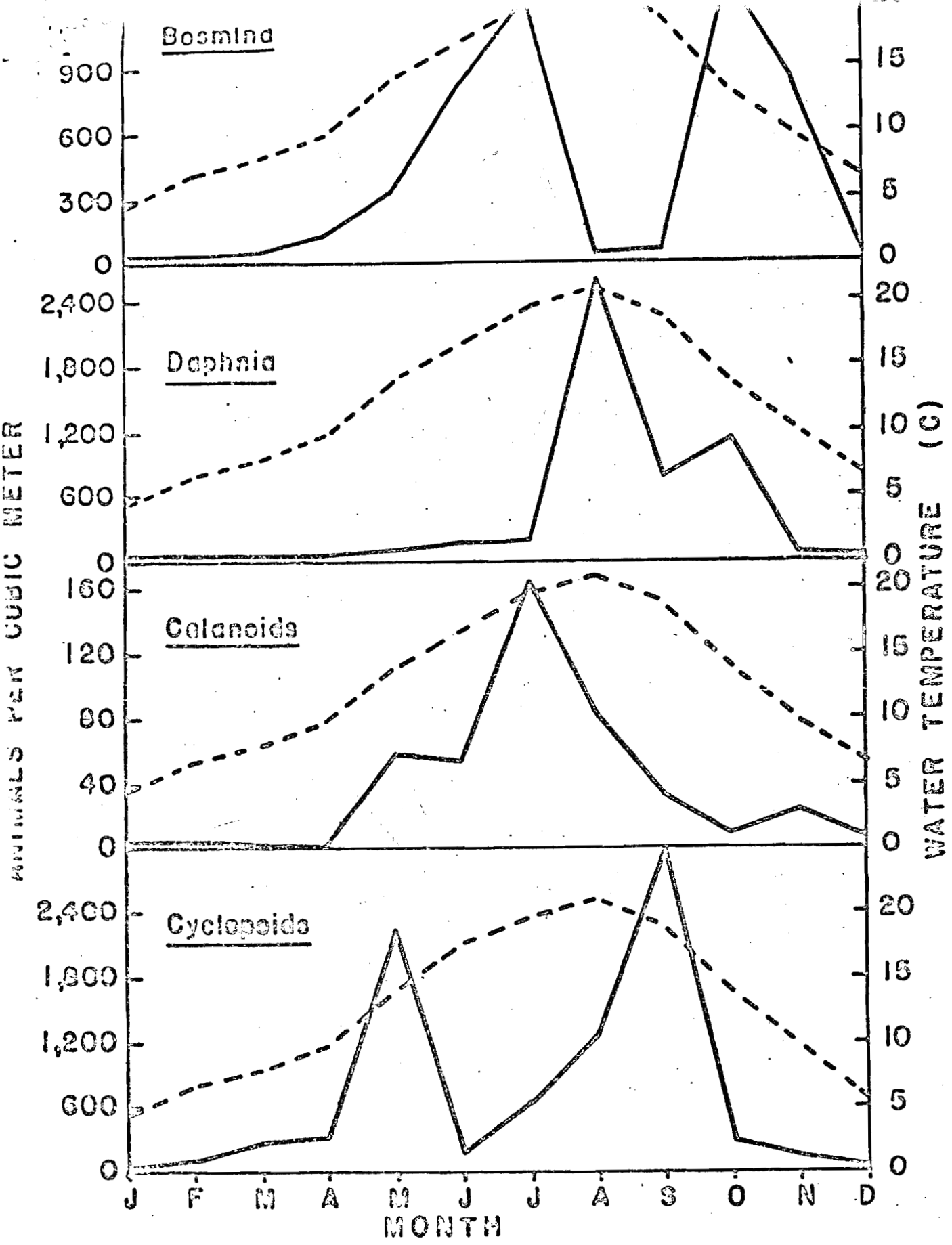


Figure 12.--Average number of zooplankton per cubic meter (solid line) and average temperature (broken line), Columbia River, Prescott, Oregon, 1968.

whereas those that were one day old when testing began and matured under test conditions had increased reproduction up to the lethal level (above 27 C). A 5 C increase in acclimation temperature had little effect in enhancing resistance to elevated temperatures. The Columbia River Daphnia seemed to be less tolerant to temperature increases than the complex from Seattle. Greatest reproduction was generally near the acclimation temperature (Craddock, MS 1970).

Thermal shock tests (acclimation temperature of 15 C) showed that a 15-minute exposure to temperatures of 30 C or less seemed to have little effect on the survival of D. pulex. A 30-minute exposure of Daphnia acclimated at 22-23 C caused a 100% mortality in less than 30 minutes at 35 C, and less than 2 days at 34 C.

Experiments with individual Daphnia showed temperature (1) had a definite effect on time to first brood, (2) practically eliminated reproduction at 30 C and above, and (3) decreased the life span as temperatures increased about 21 C (figs. 13 and 14).

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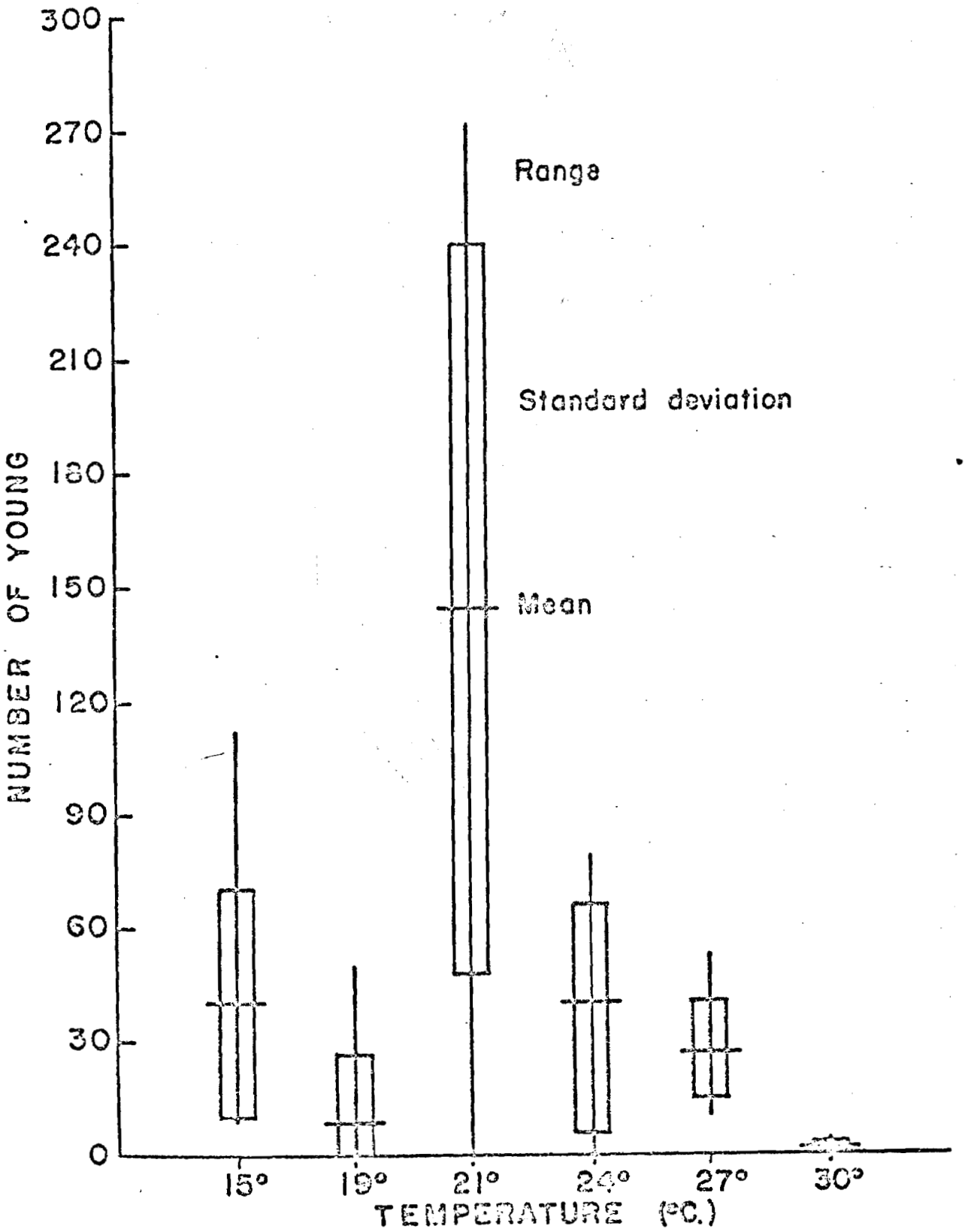

Figure 13.--Number of progeny of Daphnia pulex at various water temperatures.

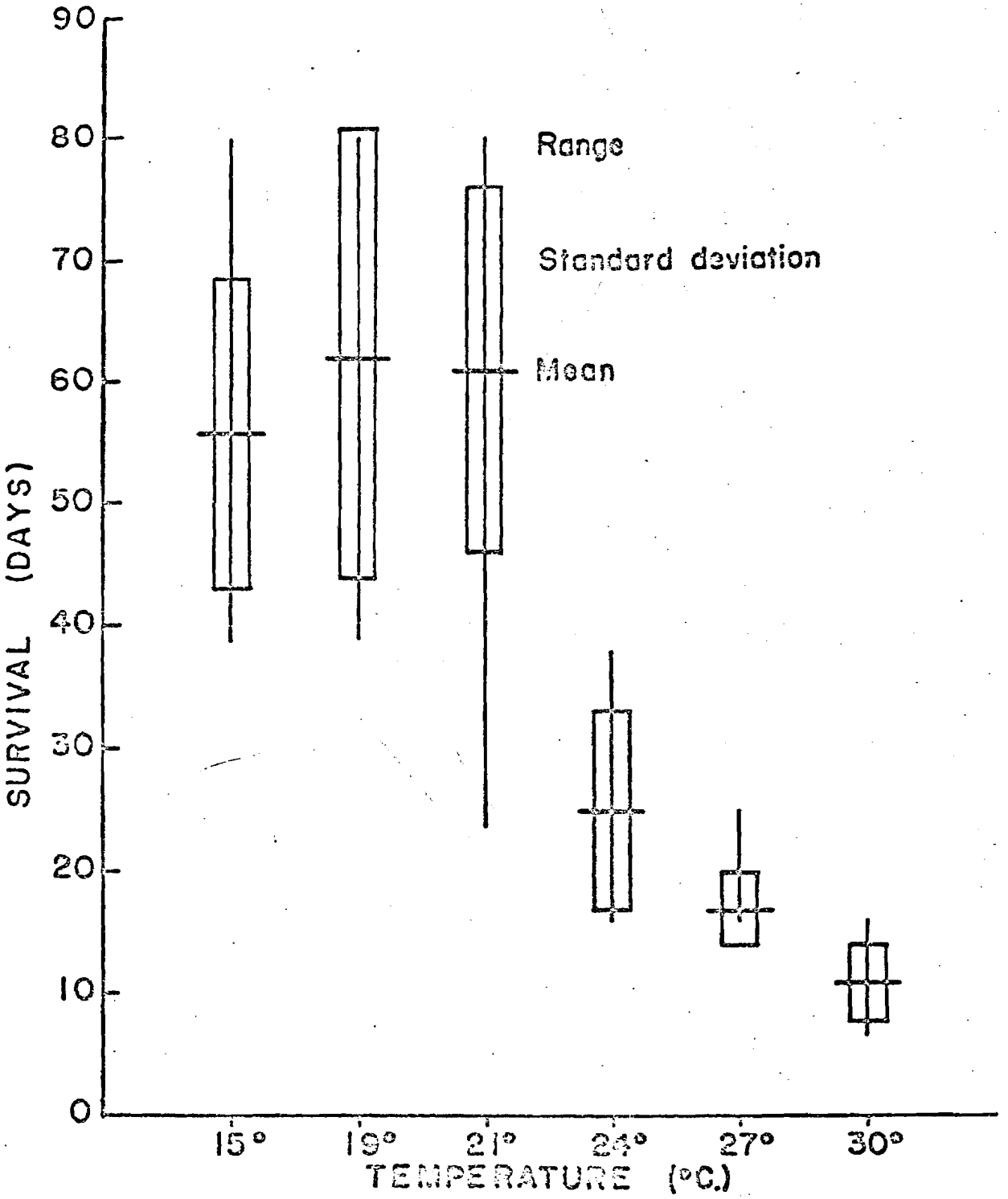

Figure 14.--Survival of Daphnia pulex at various temperatures.

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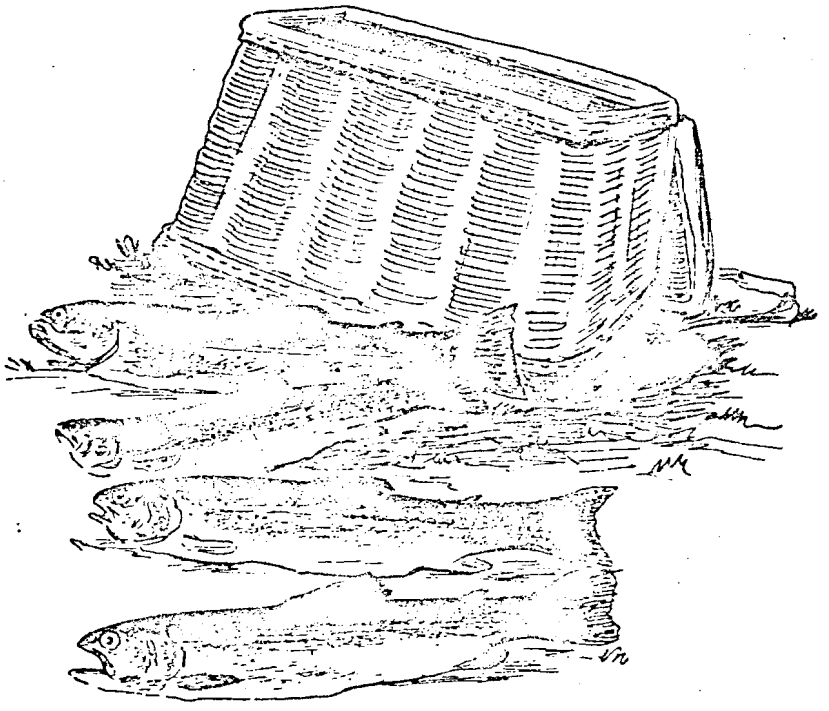
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