IMPORTANCE OF WATER TEMPERATURE IN THE MAIN STEMS OF THE COLUMBIA AND SNAKE RIVERS IN RELATION TO THE SURVIVAL OF SALMON

by

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INTRODUCTION

The relation between the distribution of separate species of poikilothermal fish and environmental temperature is very strong. Permanent shifts in the temperature regime can eventually cause changes in the species composition within the geographical area affected. The tilefish (Lopholatilus chamaeleonticeps) appeared off of the New England coast in large enough quantities to support a commercial fishery in the late 1800's. In 1882, a sharp cooling trend set in, causing mass mortalities of the species. The tilefish disappeared completely from this region.

Nikolsky (1963) states, "The cooling caused by the spread of the ice sheet at the end of the Tertiary and the beginning of the Quaternary periods enabled the representatives of the salmon family, which were adapted to cold water, to spread considerably southward as far as the Mediterranean Sea basin, including the rivers of Asia Minor and North Africa." The Pacific salmon, which has evolved as a cold-water species, is able to adapt to temporary shifts of the temperature regime it inhabits, although not without loss. A permanent temperature shift to higher levels during the fresh-water life history could result in minimal survival conditions.

The taxing demands of heavy fishing pressure, obstructions to upstream and downstream migrations, and the gradual loss of adequate spawning grounds have placed the upper Columbia River and the Snake River salmon runs in jeopardy. Instead of accepting rising temperatures in the river with resultant fish losses as a way of life, fishery agencies might well take an aggressive stand and seek the means to create beneficial rather than harmful temperature changes.

The purpose of this report is to point out the importance of water temperature as an environmental condition and the advantages to be gained by control.

TEMPERATURE REQUIREMENTS OF PACIFIC SALMON

Salmon are faced with immediate temperature problems in the main stems of the Columbia and Snake Rivers during two major stages of their life history. These are the juveniles (including fry) which have moved out of the spawning areas and the adults migrating upstream. Incubating eggs and fry in the spawning areas are generally not within reach of temperature control at the present time.

Effects of Increased Temperatures on Adult Salmon

Adult salmon make their final journey from the estuary to habitual spawning grounds on stored energy. The installation of dams on the Columbia River has eliminated the falls and rapids which may have required great expenditures of energy by the salmon during migration.

The storage of water, however, has created a situation which is difficult to assess. Water temperatures have increased due to increased atmospheric heat transfer, and adults migrating through these impoundments are, for various reasons, delayed in their journey.

The metabolic rate of all fishes is closely dependent on the temperature. The rate of metabolism will increase with an increase in temperature, even if the animal is motionless (Winberg, 1956). Synergistic effects are particularly noticeable with increased temperatures because (1) oxygen demands increase, (2) oxygen-carrying capacity of the water decreases, and (3) susceptibility to toxic substances increases. A rise in temperature from 60° to 70° F. could probably raise the active metabolic rate by onefold to fivefold (Brett, 1962). The possibility then arises that the total energy expended due to demands caused by increased temperatures and prolonged migration times may well equal or exceed that energy expended under prior conditions.

Elevated temperatures not only increase the metabolic rate and drain the reserves of energy but also drastically affect the total ability of the adult salmon to do work. Muscular activity increases, but the recuperative powers of the animal diminish.

In addition, there is evidence which shows that the sex products of adult salmon which are exposed to high temperatures during the prespawning period are adversely affected1/. Increased water temperatures decrease the rate of maturation and prolong the period of time in which the animal is exposed to fresh-water

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1/ Fulton, L. A. The effect of temperature on incubating eggs, juvenile, and adult salmon, a literature survey. Bureau of Commercial Fisheries, Fish-Passage Research Program, Seattle, Washington. Unpublished report (1963).

dangers before the eggs are deposited. Diseases such as Chondrococcus columnaris become highly virulent when the water temperatures reach the upper 60's and low 70's (°F.), seriously infect large numbers of adult salmon, and have been suspected to be the principal cause of declines in the Redfish Lakes sockeye salmon runs (Ordal and Pacha, 1963).

Optimum Temperature Conditions for Adults

Maximum productivity of adult salmon during the fresh-water stage is achieved in the temperature range of 42.5° to 55° F. (Burrows, 1963). This is the optimum range for adult survival, egg viability, time of spawning, and spawning efficiency. Although fall chinooks in the Columbia and Snake Rivers are faced with, and actually survive, temperature ranges of 65° to 75° F., the maximum during migration and maturation should be 60° F.

When other environmental conditions, such as turbidity and stabilized water flow, are optimum, there is no question that water temperatures in the optimum range of 50° to 60° F. can definitely benefit the adult salmon population. The most striking example of this is the chinook salmon runs in the upper Sacramento River after the construction of Shasta Dam and Keswick Dam (reregulating).

The most significant effect of Shasta Dam is the profound change in the temperature regime downstream (fig. 1). Prior to impoundment, temperatures dropped as low as 42° F. in the winter months and reached a high of 72° F. in the summer months. The temperatures below the dam are now higher in the winter and lower in the summer, maintaining a narrow range between 50° and 60° F. Other environmental features were also altered to the salmon's benefit. Flow patterns were smoothed, and turbidity decreased considerably. This significantly improved the more than 90 miles of excellent gravel bottom in the river bed below Keswick Dam. The decreases in river temperatures, in addition to the other advantageous environmental features, have influenced the spring chinooks to remain in the main river and spawn, avoiding the collection racks at Keswick Dam. In 1943, examination of dead females showed 95 percent spawning success. In 1944, spawning success was 67 percent, this lesser success being caused by mine pollution in the immediate vicinity of Keswick Dam; and in 1945, spawning success was 98 percent.

In 1946, the commercial catch of California king salmon was 13,700,000 pounds, a 31-year record. This phenomenal catch attributed to the success of the 1941, 1942, and 1943 year

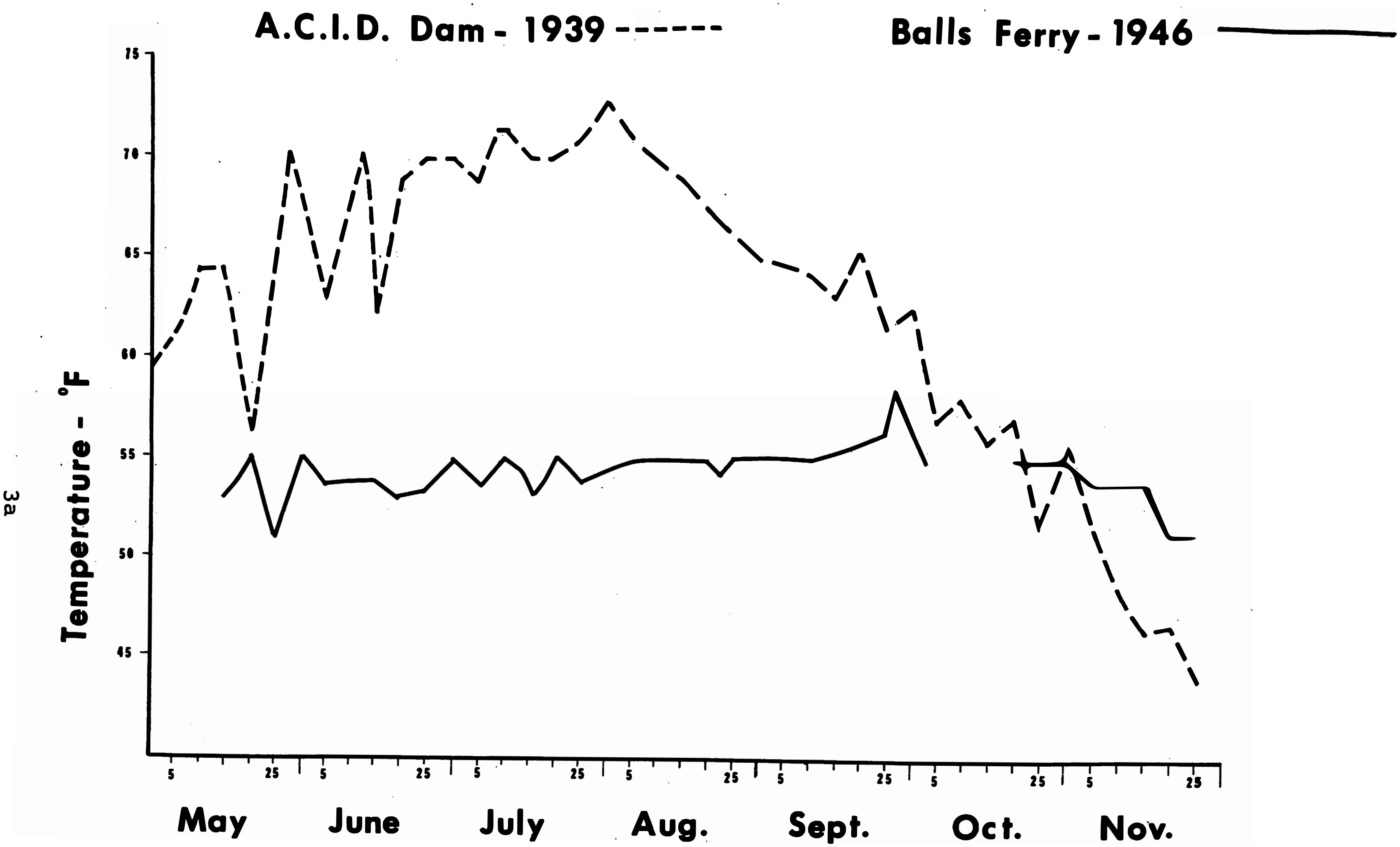

Figure 1.--Pre- and post-impoundment water temperatures of the Sacramento River below Keswick Dam. From Moffett (1949).

classes. In addition to advantageous conditions for adults, other factors of a desirable nature were noted. Egg incubation was accelerated. Time of migration of juveniles is now ahead of maximum irrigation usage. River food production for juveniles has increased, owing to higher winter water temperatures and stabilized flow. Most significantly, the scrap fish and predatory nonsalmonid species have virtually disappeared.

The thermal cycle of the upper Sacramento River was once borderline habitat for salmon. It now conclusively resembles thermal cycles of streams which are in the center of the geographical range of chinook salmon (Moffett, 1949). More recently, it has been noted that the Sacramento River is the only river on the continent which has definitely established three separate runs of king salmon: fall, winter, and spring (Slater, 1963).

The Effects of Increased Water Temperatures on Juvenile Salmon

The upper lethal temperatures for juvenile salmon of all five species do not vary by more than 1° to 2° C. However, the juveniles of each species have other temperature relationships which have evolved as adaptions to the environment. The optimum cruising speeds for young sockeye, for example, are found at 15° C., whereas coho performance is best at 20° C. In British Columbia, sockeye feed and live in the cooler limnetic water of lakes and migrate out before lake outflow temperatures reach 14° or 15° C. Young coho feed and live in the littoral zone of the lakes and ascend small tributary streams, where waters sometimes get quite warm. Outmigrations of coho may coincide with the juvenile sockeye, but will frequently continue on long after the sockeye have left (Brett et al., 1958).

Lower water temperatures reduce the effects of most diseases on juvenile salmon with the exception of *Cytophaga psychrophilia,* a myxobacterium. As the temperature rises above 15° C., the virulence of certain strains of *Chondrococcus columnaris* increases rapidly (Ordal and Pacha, 1963). Resistance to pollutants, both organic and inorganic, generally decreases with increased water temperatures. As water temperatures rise, the respiration and metabolic rates rise. Circulating blood is exposed at a faster rate and noxious chemicals enter the system at a rate which exceeds excretory removal. Here again, the synergistic attacks upon the physiological functions become complicated. With increased water temperatures, the oxygen carrying capacity of the blood decreases, metabolic demands for oxygen increase, and the oxygen levels in the water decrease. Subjection of fish to minute quantities of pollutants during these stresses can be disastrous.

Optimum Temperature Conditions for Juvenile Salmon

There are so many synergistic effects associated with decreased water temperatures in regard to juveniles that the absolute assessment of the benefits derived is a difficult task. Only the highlights are presented here.

The amazing results in the Sacramento River have already been noted. Hoar (1948) has stated that changes in the water temperature or changes in the periodicity of thermal cycles produce notable reactions in juvenile salmon, some of which are associated with seaward migration. Warmer water during the winter months throughout the habitat will accelerate embryonic and fry development and consequently alter the time of migration.

The effects of water temperature changes during downstream migration are of great importance. In recent years it has been demonstrated with pink salmon that the environmental temperature at the time of downstream migration through the estuary is correlated with the strength of the returning year class. There has been no such effort to measure or correlate the strength of the returning year class with estuarine environmental conditions in the Columbia River at the time of downstream migration.

Variations in evolved temperature zone habitation are confirmed by laboratory temperature preference tests. The final preferendum temperature for juvenile sockeye is 14.5^{o} C.; for chinooks, 11.7^{o} C.; for chums, 14.1^{o} C.; and for pinks, 11.7^{o} C. (Ferguson, 1958). Optimum growth of juveniles is achieved at the preferential temperatures, and for all species of Pacific salmon this would be within the range of 10 to 15^{o} C. (Burrows, 1963).

TEMPERATURE REQUIREMENTS OF OTHER SPECIES OF FISH IN THE COLUMBIA AND SNAKE RIVERS

Increased changes in the temperature regime or shifts in the thermal cycle can influence the balance of other species of fish in the system as well as the salmon.

The classical effects of the influences of cold-water releases from Shasta Dam on the Sacramento River salmon are just as applicable to other fish species. Studies of sport fishing efforts show that the resident trout populations have increased, whereas species such as bass, catfish, and sunfish--which compete with trout for food and space--have decreased (Moffett, 1949).

Species Inhabiting Warm Temperature Zones

The predacious squawfish (*Ptychocheilus grandis*), once the dominant carnivore in the Sacramento River, has been driven from many miles of stream below the dam. It has become dominant in smaller streams which are experiencing a warming trend (Taft and Murphy, 1950). The preferred temperatures of squawfish, based on various field observations, appear to be from 16° to 25° C., with a lethal high of 29° C. The temperatures in the Columbia and Snake Rivers are well within the preferred range of the squawfish for at least several months each year (fig. 2). There appears to be a strong correlation between the incidence of highly virulent strains of *C. columnaris* and squawfish population buildups in the Columbia River near Richland, Washington, during high-temperature periods (Ordal and Pacha, 1963).

Cyprinids, such as *Cyprinus carpio*, are the dominant forage fish in the mainstems of the Columbia and Snake Rivers. Carp do best in extremely warm waters, near the upper limit of their preference range (20° to 32° C.). They will continue to feed actively until water temperatures drop to 8° C., and will not begin their annual spawning until the temperatures rise again to at least 15° C. (Nikolsky, 1963). They usually seek out shallow bays late in the spring as spawning sites. These are the first areas to warm. The many sloughs and the shallow littoral zone behind McNary Dam, for example, make this reservoir particularly productive. Largemouth bass (*Micropterus salmoides*) also favor waters in the upper twenty degree centigrade range and are common in the quiet back bays and the warm shore areas of some of the reservoirs. The smallmouth bass (*M. dolomieui*) is more commonly found in the rocky sections of the Snake River, especially in Hell's Canyon. Optimum spawning conditions are achieved when the water temperature suddenly accelerates to 16° C., or higher, and is held there for at least 3 weeks. Spawning successes below 16° C. are extremely doubtful (Macan, 1963). Both the smallmouth bass and the perch (*Perca flavescens*) prefer water temperatures in the low twenties (centigrade). Perch will spawn at lower temperatures, but members of the sunfish family--such as *Lepomis gibbosus*--require minimum temperatures of 22° C. for spawning, their habits being quite similar to those of the largemouth bass.

Species Inhabiting Intermediate Temperature Zones

Most of the aforementioned species would suffer the severest setbacks in those areas where water temperatures are held back to 16° C. or less during the early summer months, owing to disruption of spawning cycles. Trout, whitefish, and some species of suckers would undoubtedly benefit by the presence of colder water during the summer months (fig. 2). Carside and Tait (1958) found that rainbow trout which were acclimated to cold water preferred to move into warmer waters as the acclimation temperatures approached or exceeded 13° C. The final preferential temperature was 13° C. Brook trout, which are not common in the main stems, are most active between 13° and 16° C., and maximum growth is achieved at 13° C. (Macan, 1963).

Members of the bullhead family (Ictaluridae) are active at all temperatures between 10° and 34° C. Their population limitations are similar to those of the sturgeon. Both groups are bottom feeders and prefer silty conditions and deep holes, where dead insects and organic material collect.

CONCLUSIONS

The main stems of the Columbia and Snake Rivers are now, thermally speaking, borderline habitat. That is, the temperature ranges are not optimum at the present time for most of the warm-water species, nor are they optimum for the development of a highly productive trout and salmon environment.

On the basis of evidence at hand, there is no question but that fishery agencies must take advantage of every situation where cold water can be introduced into the system during the summer and early fall months. In addition, if warm waters can be introduced during the winter months, it is not unlikely that improved water quality similar to that of the Sacramento River will develop.

The present trend of gradually increased temperatures could continue upward with the addition of reactor power stations. VonGunten[1/] has stated that the installation of one 100-million-kilowatt thermal reactor power plant would raise the temperature of the Columbia River at The Dalles 9.4° C. (17° F.). A temperature

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1/ U. S. Corps of Engineers, Walla Walla District. Personal communication (1964).

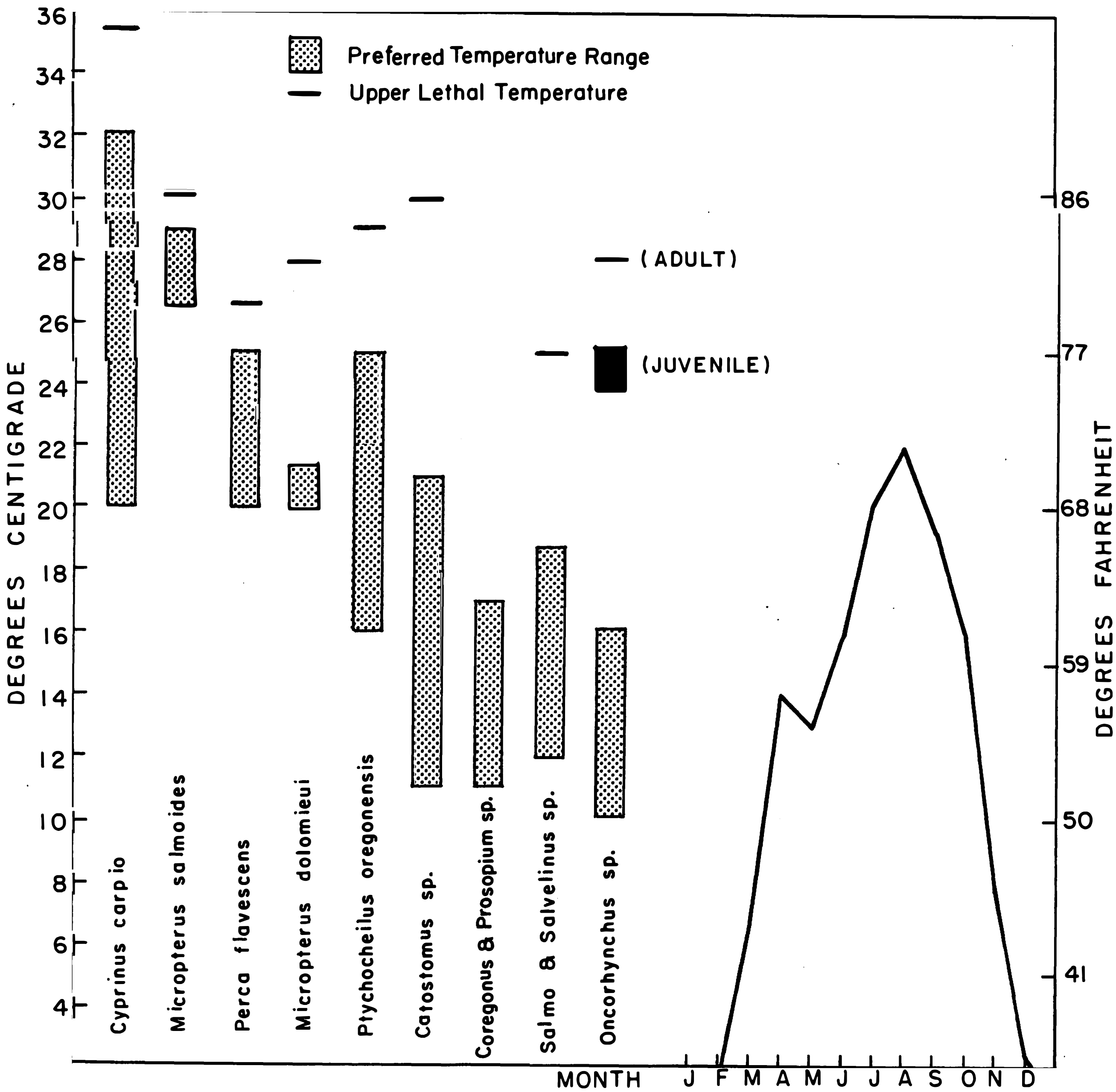

Figure 2. Preferred and lethal temperatures of some Columbia Basin fish compared with lower Snake River water temperatures. Temperatures were recorded at the mouth, and monthly averages for 1954 to 1957 combined.

rise of this magnitude would certainly place a large segment of the river beyond the range of the thermal requirements of the salmon.

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