BNWL-SA-3876

Conf-710501--5

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ECOLOGICAL EVALUATION: MIGRATION OF JUVENILE SALMON IN RELATION TO HEATED EFFLUENTS IN THE CENTRAL COLUMBIA RIVER[1]

by

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Running Head: Juvenile Salmon and Heated Effluents

For: Third Nationtal Symposium on Radioecology, Oak Ridge, Tennessee, 10-12 May, 1971

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[1] Support for Thermal Effects Studies in the Columbia River at Hanford, Washington is provided by the U.S. Atomic Energy Commission under Contract AT(45-1)-1830 with Battelle Memorial Institute, Richland, Washington.

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DISCLAIMER

ABSTRACT

Field investigations to evaluate the effects of heated reactor discharges on juvenile salmonids passing seaward through the central Columbia River at Hanford were conducted from March to September, 1968 and 1969. Test fish held in liveboxes were drifted through the discharge areas while the encountered thermal dose (i.e. temperature increase and exposure duration) was monitored. Some mortalities resulted in shoreline drifts through areas receiving heated water via intragravel seepage from effluent retention basins. Mortalities during drifts through the main discharge plumes in midriver were insignificant except under late summer conditions. The contrasting effects between the two sites were due primarily to differences in effluent mixing patterns. Environmental features regulating thermal effects, which varied over the migration season, were prevailing river temperatures (4-20° C) and discharges (40,000 - 200,000 ft^3/sec). Four seasonal combinations occurred in sequence with increasing potential for thermal damage: low temperature and low discharge (early spring, low temperature - high discharge (late spring), high temperature - high discharge (early summer), and high temperature - low discharge (late summer). Juvenile salmonids produced in the Hanford area migrate seaward from April to July when low river temperatures and(or) high discharges are favorable, but delayed migrants originating above Hanford encounter less favorable conditions in July and August.

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INTRODUCTION

Plutonium production reactors on the Atomic Energy Commission's Hanford Reservation above Richland, Washington use Columbia River water as a coolant. The diverted water, when returned to the river, has been heated to the extent that prolonged exposure to the unmodified effluent would be lethal to most species of freshwater fish. However, the central Columbia with its large flow volumes and cold currents has the physical capacity to absorb relatively vast amounts of heat. As a result river temperatures at Preist Rapids Dam, above Hanford, and at Richland, below Hanford, normally differs by less than 2-3 degrees. The areas of greatest hazard to juvenile salmon are in the immediate vicinity of the effluent discharges where initial mixing occurs and temperatures are highest.

Heated effluents at Hanford issue primarily from submerged outfalls located near midriver. Some areas along the south bank of the river where the reactors are located also receive heated water via intragravel seepage from shoreline retention basins and from test disposal of effluent into the ground. Temperatures at the discharge points rise sharply before the effluents become dispersed in the receiving river water. These areas are potentially lethal to young salmon by exposing a portion of the migrating fish to "thermal shock" as they pass seaward through the central Columbia each spring and summer. Resulting mortalities could occur in three ways, depending on the extent of thermal exposure and the thermal resistance of the species involved, namely: 1) immediate, direct losses; 2) delayed, latent losses; and 3) indirect losses through predation, disease, and lowered resistance to environmental stress. Under field conditions during this study, only immediate and delayed mortalities could be staisfactorily determined.

This report presents observations and data obtained during livebox drifts of caged juvenile salmonids through effluent discharges at Hanford in 1968 and 1969. The objectives were to: 1) determine if, under simulated natural conditions, passage through areas of thermal discharge killed young salmonids and 2) examine the physical parameters, i.e. temperature levels and exposure durations, that were encountered *in situ* by the fish. The information presented herein has been assembled in detail in internal reports of limited distribution (Becker and Coutant, 1969; Becker, Coutant and Prentice, 1971), and are but one portion of an integrated program of laboratory and field studies to evaluate the biological consequences of the Hanford operations.

MATERIALS AND METHODS

General procedures involved the placement of juvenile salmonids in liveboxes and drifting test groups through effluent mixing zones; control groups were treated similarly but drifted in paths avoiding thermal exposure. The experimental fish consisted primarily of egg-sac fry and 0-age chinook salmon *Oncohrhynchus tshawytscha*), but included some yearling coho salmon (*O. kisutch*) and yearling rainbow trout or steelhead (*Salmo gairdneri*) when available. The methods described herein are based primarily on the refined 1969 field operations. The drift sites and reactor discharge locations are shown in Figure 1.

The drift procedures can be summarized as follows: 1) Fish were retained in floating acclimation pens downstream from the heated discharges for several days to permit predrift acclimation to river conditions; 2) Groups of test fish, usually consisting of 20-25 individuals, were placed in liveboxes attached to each side of a drift boat; 3) Groups of control fish were proportioned similarly in a second drift boat; 4) The drifts were conducted by guiding test fish through effluent mixing zones and control fish through unmodified areas at river flow rates; 5) Any immediate mortalities at the end of the drifts were noted; 6) Test and control fish were held six days postdrift in floating pens situated downstream and inshore of the mixing zones, and examined daily for delayed mortalities; 7) Survivors were released.

A livebox consisted of a tubular metal frame about 46 cm^2 covered by a rubberized mesh with 1/2-inch diamond perforations. Small fry were placed in containers constructed of plastic window screen within each livebox, since they could pass through the rubberized mesh, while large fingerlings were permitted to move freely. Fish were drifted either near the surface or at a 3 meter depth. The depth of subsurface drifts was controlled by installing a 20 ft. pipe, which could be shifted from a horizontal to a vertical position, to the side of each drift boat and the livebox was raised or lowered by a pully and rope apparatus. The sensitive probe of a thermal recorder was inserted in each livebox. The probe (No. 49, Yellow Springs Instrument Company) had a time constant of 1.7 seconds, i.e. the time required to register 63 percent of a sudden temperature change. Temperatures were read directly on multirange Tele-Thermometers (Model 46 TU, YSI), and permanent records of temperature fluctuations were made on strip chart recorders.

Drifts commenced above the heated effluent discharges and terminated below the "thermal pulses", which indicated fluctuating temperatures of the primary mixing zones as well as exposure of fish to mixing discharges. Drifts were conducted at rates equivalent to surface flow through areas representing maximum mixing temperatures, determined visually. The foci of discharge plumes in midchannel appeared as intermittant boils breaking the river surface, while seepages were evident as areas of trickling water and rising vapors along the shore. In order to encounter the most strigent conditions, most drifts were conducted during early morning hours to correspond with minimum daily river discharges as regulated above Hanford at Priest Rapids Dam, a hydroelectric project.

BIOLOGICAL AND ENVIRONMENTAL CONSIDERATIONS

Field studies to evaluate thermal effects on transitory fish populations such as the young of anadromous salmon must consider biological and environmental features. To do otherwise would present data in an erroneous light, mask its full ecological implication, and nullify much otherwise valuable information. Two qualitative considerations were of paramount importance in this study. First, the precise timing of the annual seaward migration of young salmonids in the central Columbia and, second, the transition of river temperatures and discharge volumes during the migration season.

Seaward Migration Timing

The timing of the annual seaward migration of young chinook salmon in relation to possible effects of thermal discharges (Becker, 1970) is essentially as follows. In earlier years before full implementation of the upriver reservoir complex, juvenile chinook passed through the

Hanford area during the spring and early summer. In 1955, for example, the migration showed two peaks, the first (mostly fry) occurring in March and April and the second (mostly fingerlings) in June and July (Mains and Smith, 1964). However, fish originating above Priest Rapids Dam at the present time pass through Hanford at a later date, primarily in July and August (Park, 1969). Construction of hydroelectric dams and filling of reservoirs during the past decade is assumed to be responsible for the delay since fish migration rates are reduced in the relatively slack water habitat of impoundments (Raymond, 1968, 1969). Data obtained when seining juvenile chinook for food studies (Becker, 1971) indicate that those fish produced in the Hanford section retain their historical migration pattern and that most have passed downriver into the McNary Dam impoundment (below Hanford) by mid-July; since the Hanford section (93 km long) remains free-flowing, there is no basis to believe that this normal timing has been altered.

Juvenile chinook now leaving the central Columbia, therefore, can be separated into two components on the basis of migration pattern (Figure 2). Those produced in the Hanford environs retain their historical timing whereas those originating above Hanford in tributaries, hatcheries and spawning channels may be impeded up to two months. The delayed migrants encounter late season environmental conditions in July and August (i.e. warm temperatures and low flows), which largely were avoided in earlier years.

Temperature and Discharge Volumes

The annual cycles of temperature and discharge in the central Columbia remain essentially similar from year to year, with temperatures rising during the spring and river flows increasing then decreasing during the annual spate. However, weekly and daily variations in discharge volumes now occur from regulatory releases at upriver dams. In 1969, the spring rise in river temperatures followed the usual pattern (Figure 2). Temperatures were well below preferred levels for juvenile salmon in March and April when young chinook emerged from the gravel of the river bed, entered the preferred range of 12-14° C (Brett, 1952) where thermal conditions are presumably near optimum in late May and early June, and extended into the upper zone of thermal tolerance in July and August. In 1968 and 1969, mean weekly water temperatures peaked in late July, August and early September with maximum daily temperatures briefly reaching 19.1 and 19.7° C in the two years, respectively, at Priest Rapids and 19.7 and 20.6° C at Richland.

An upper incipient lethal level of 25.1° C has been established for young chinook and coho salmon in the laboratory (Brett, 1952), but this level is being redefined for Columbia River fish. However, temperatures exceeding 20° C may well be considered suboptimum for sustained survival of juvenile salmonids in the river ecosystem. It was later proposed (Brett, 1960) that the upper limit of required temperatures for any species of fish should not exceed that which would curtail activity below 3/4 of optimum, and a "freedom" of 3° C (5.5° F) below the ultimate lethal level was recommended. Temperatures in the central Columbia rarely exceed 22° C and have never been recorded near the 25° C lethal level.

River discharges in 1969 (Figure 2) began to increase about 6 weeks earlier than in 1968, because of construction releases from Lake Roosevelt behind Grand Coulee Dam far above Hanford, and high flows were sustained for a longer period. Discharges decreased rapidly in July, as usual, and low flows prevailed in August and early September. Since the data illustrated in Figure 2 are based on weekly means, they fail to reveal either weekly or daily fluctuations that occur from flow regulation at Priest Rapids Dam immediately above Hanford. Flows are usually reduced on weekends and increased during the week to satisfy consumptive demands for hydroelectric power. For similar reasons, flows are decreased at night and increased during the day. Weekend variations occasionally result in changing the level of the river flowing through the Hanford section up to 5 ft in a 12 hr period.

Mean daily discharges at Priest Rapids Dam from March through April, 1969 are illustrated in Figure 3. Day to day fluctuations were less pronounced in April, May and early June because increased runoff from snow melt (combined with Grand Coulee releases) provided a seasonal surplus of river water. In March and later in August, however, the available water was conserved in the Priest Rapids reservoir and weekend decreases in discharges were more extreme.

The importance of river discharges during the migration of young salmonids through Hanford is that they influence the extent of possible thermal exposure in mixing zones. For relatively constant effluent volumes, high flows dilute and disperse the heated effluent more efficiently than low flows. Moreover, with high discharge volumes the migrating population spreads over a wider horizontal area and the proportion of fish that may involuntarily enter the mixing zones is presumably reduced.

DRIFT RESULTS

Summary of Data

The drifts were conducted during two crucial periods for evaluating thermal effects: the early spring, when river temperatures were low and fish were small (35-50 mm long), and the summer, when river temperatures were high and the fish were large (70-95 mm long). These periods (Figure 3) were characterized by low flows and were separated by the annual spring spate (discharges >200,000 cf/sec) when nitrogen supersaturation in the river inserted a stress factor that tended to bias thermal effect studies.

Accumulated data on the thermal experience of drifted fish, drift locations, temperature and exposure durations, and resulting fish survival or mortality rates form an expansive array of tables and figures that are provided in detail in Battelle-Northwest reports (Becker and Coutant, 1969; Becker, Coutant and Prentice, 1971). It is mandatory to condense this information for presentation here.

Data for the 1968 and 1969 drifts are summarized in Figures 4 and 5, respectively, where the base river temperature is given on the ordinate and the maximum temperature encountered by drift groups is on the abscissa. The diagonal line represents an assumed ultimate incipient lethal level of 25.0° C and is the sum of any combination of ordinate and abscissa readings. Maximum temperatures (thermal shock) fall either in the zone of thermal tolerance or the zone of thermal resistance. Although temperatures in the zone of thermal resistance are ultimately lethal, young salmon can theoretically survive in this zone for a limited time, which is essentially a function of the distance of the exposure temperature beyond the incipient lethal level (Fry, 1964).

No significant losses occurred during the 1968 spring drifts (Figure 4). The 1969 spring drifts were scantily represented (Figure 5) because of heavy losses involving test and control fish from "gas bubble disease" during the postdrift retention period in late April and May; this was a consequence of high nitrogen levels in the river that resulted from increased discharges over spillways at Priest Rapids Dam at an earlier than usual time. Although exposures to potentially lethal temperatures (thermal shock) occurred during three 1969 spring drifts through a shoreline seepage area below the BC reactor, the exposure duration (thermal dose) was sufficient to cause thermal mortality in only one test group. Temperatures and exposures in all drifts through midriver plumes were insufficient to cause thermal mortality. Mitigating environmental conditions, i.e. low base river temperatures (4.0 - 8.0° C) and increasing river discharges, were the primary reasons for the general lack of thermal deaths during the spring drifts.

Significant losses occurred among three groups of test fish drifted during the summer of 1968 (Figure 4). These drifts involved prolonged exposure to heated water (up to 40 min) from shoreline seepages, but the maximim exposure temperature reached the zone of thermal resistance in only one area, below the BC reactor. None of the 1968 summer drifts through midriver plumes, where passage was rapid and exposures were brief, caused thermal losses. Four summer drifts in 1969 resulted in near total mortality, two through an inshore leak by the K reactors and two through the main K plumes in midriver (Figure 5). However, a lethal thermal dose did not result in the majority of drifts through the K reactor plume, albeit environmental conditions were extreme, i.e. relatively high base river temperatures and low river discharges (Figure 2). Exposure durations were normally too short to cause mortalities even when maximum temperatures exceeded the arbitrary 25 C lethal limit. In 1968 and 1969 combined, three summer drifts where the fish encountered peak temperatures only in the tolerance zone caused high mortality for reasons inadequately known.

Shoreline versus Midriver Discharges

The physical parameters of drifts conducted through shoreline areas receiving heated effluent contrasted with those through the midriver plumes. These differences were related to thermal effects among test fish. Generally peak temperatures were higher and exposure durations were longer in shoreline drifts and thus seepage areas held a greater potential for causing fish death.

Shoreline drifts were characterized by 1) prolonged exposures of test fish to mixing effluent, because of a slow drift rate resulting from restricted downriver flow; 2) high thermal doses, because of a reduced mixing rate of the effluent in the receiving river water; and 3) gradual temperature declines, because of an extended primary mixing zone. Inertial effects along the shore clearly contribute to reduce the efficiency of the mixing process.

Midriver drifts through the main discharge plumes were characterized by 1) brief exposures of test fish to mixing effluent, because of a rapid drift rate; 2) low thermal doses, because of an increased mixing rate of the effluent; and 3) rapid temperature declines, because of a shortened primary mixing zone. Exposures to peak plume temperatures in midriver drifts usually occurred within a few minutes of initial contact. Recorded exposures to fluctuating temperatures, which indicated the transition zone below the plumes, occurred within ten minutes even at minimum river flows. After initial contact with the plumes, the intensity and fluctuation of effluent temperatures dropped rapidly to harmless levels.

DISCUSSION

Mortality of juvenile salmonids under simulated migration conditions is primarily a function of thermal experience, i.e. temperature increase and exposure duration (= thermal dose). These integrated functions determine the lethal effect, if any, of "thermal shock" as the fish pass downriver through the effluent mixing zones. Clearly if the temperature is sufficiently high and the exposure duration is sufficiently long, any species of fish shocked by heat will be killed. The precise relationship has been determined in laboratory experiments, but extension of these data to field conditions is questionable because temperature fluctuations occur randomly in the mixing zones before thermal stabilization occurs. Moreover, unknown intrinsic factors are often operative in field situations that are largely reduced or eliminated in controlled laboratory studies. An ideal evaluation program (for thermal effect studies) must combine laboratory and field data in order to obtain ecological meaning with respect to the survival value for a species (Mihursky and Kennedy, 1967).

Environmental conditions when juvenile salmonids are migrating clearly influence thermal experience, potential or realized. The two most important features in the central Columbia River are prevailing river temperatures and discharges, which annually range from about 4 to 20.0° C and 40,000 to 280,000 ft^3/sec, respectively. On the basis of our observations and experiments, the potential hazard to migrating fish from heated discharges apparently increases from March through August.

Low Temperature - Low Discharge (March-April)

River temperatures and flow volumes are low during early spring. Chinook fry first emerge from the gravel in the Hanford environs at this time. Many weakly swimming fry are apparently carried downriver, thus contributing to an early seaward migration as detected by Mains and Smith (1964). Other fry appear in inshore areas for variable periods of feeding and growth before departing seaward (Becker, 1971). The livebox drifts reveal only one instance of excessive mortality during early spring when fish were passed through a shoreline seepage area, but no losses from midriver plumes. The absence of lethal effects, either immediate, direct losses or delayed, latent losses from thermal dose, is due largely to prevailing low river temperatures.

Surface mixing patterns of the K reactor plume at flows of 41,000 and 80,000 cf/sec, taken by infrared imaging (Jaske, Templeton and Coutant, 1970) are shown in Figure 6. Maximum thermal increments cover a broader surface area behind the plume at the lower flow, and the width of the 1-6° C ΔT mixing zone extending downriver is wider. If base river temperatures are low, as in early spring, increments sufficient to cause death exist only in the plume focus. If midriver currents are rapid, as in the central Columbia, exposure to maximum temperatures would necessarily be brief and usually import merely a sublethal thermal dose. Exposure, at least of confined fish, to high temperatures in shoreline areas is longer and deaths may result.

Low Temperatures - High Discharges (May-June)

A rise in river temperature to about 16° C occurs in late spring and early summer, but high river discharges also accompany this rise.

Many juvenile salmonids are passing seaward and fish are abundant in inshore feeding areas at Hanford. Although river temperatures are near optimum, dissolved nitrogen becomes an additional environmental hazard when surplus water is passed over the spillways of hydroelectric dams, as had been the case in recent years (Ebel, 1970).

Surface mixing patterns of the K plume reactor plume at a flow of 110,000 ft^3/sec are also shown in Figure 6. Maximum temperature increments (6-9° C ΔT) occur only at the discharge focus, and the width of the mixing zone extending downriver is narrow. However, river flows during spring runoff normally exceed this level twofold and actually peaked above 270,000 ft^3/sec in 1968 and 1969. Extremely high flows protect migrants from thermal exposure in a plume by rapidly dispersing heated effluents in the vast water mass.

High Temperatures - High Discharges (June-July)

River temperature exceed the preferred temperatures for young salmonids in early summer, but discharge volumes normally remain high until mid-July. High nitrogen levels persist until river flows decrease. Most fish produced in the Hanford reach, adhering to their ancient migration pattern, pass downriver towards the sea by mid-July. High discharges mitigate against excessive losses of migrants during this period. Our drift data, however, indicate that shoreline seepages remain potentially lethal because flow inertia reduces mixing efficiency of effluents along the shore and prolongs fish exposure.

High Temperatures - Low Discharges (August-September)

High temperatures (near 20° C) and low discharges (<100,000 ft^3/sec) prevail in late summer. Whereas most juvenile chinook produced from natural spawning at Hanford have departed (Becker, 1970, 1971), a delayed passage of young salmon produced above Hanford may continue through August (Park, 1969); presumably these fish do not linger in the free-flowing Hanford section but pass through at a rate approximating the current flow. Some losses of drifted fish from thermal dose in the plumes did occur during late summer, particularly during low flows on weekends when surface mixing patterns similar to those at 41,000 ft^3/sec (Figure 6) prevailed. Temperature levels during late summer are high rather than low as in early spring, and when the base river temperature is 18° C, increments of 7° C and above will expose migrants entering the discharges to lethal thermal levels. Then whether or not mortality occurs depends on the duration of exposure.

Thus a potential for thermal mortality clearly exists in late summer, and the delayed migrants originating above Hanford are most vulnerable. Yet significant losses of test fish occurred only during two plume drifts in midriver, presumably because of relatively brief exposures to mixing effluents. Shoreline seepages were more hazardous under late summer conditions, but we have no evidence that unconfined, large juvenile fish, if present in the river, would either linger in these warmed areas and be killed.

General Conclusions

Our studies permit some generalized conclusions about thermal effects of recent Hanford operations on seaward migrating salmonids. Clearly these conclusions are based on biological and environmental features peculiar to the central Columbia River. An interpretation of the relationship of environmental characteristics to potential thermal hazard to juvenile salmonids is presented in Figure 7. Hazard increases as river temperatures rise and discharges drop. Most juvenile salmonids produced in the free-flowing Hanford section migrate seaward from April to July under corresponding conditions of relatively favorable river temperatures and high river discharges. Conditions for delayed migrants are less favorable.

The thermal hazard represented by a midstream plume appears to be less than a shoreline discharge. Potential harm depends upon ambient river conditions (temperature and discharge) and whether the fish actually enter the focus of a plume before mixing reduces effluent temperatures to sublethal levels. During active migration, juvenile chinook in the central Columbia prefer the surface zone (44% pass within 30 in of the surface) and, although the fish are horizontally distributed across the entire river, the greatest concentrations pass near the shore (Mains and Smith, 1964). In the central Columbia, where midriver current velocities exceed the swimming speed of young salmonids, collision with discharges effluents may be unavoidable for at least some fish. The proportion of migrants entering the mixing zone of a plume is unknown but this proportion is probably small due to the low ratio of effluent volume to total water mass. The number of fish that encounter lethal temperatures near the focus of a plume is likely even less, since plume temperatures generally lose 80 percent of ΔT within 5 seconds of discharge. If lethal temperatures are encountered in the initial moment of thermal shock, exposure time is normally so brief that there is little effect on sensitive fish tissues in most field situations.

Shoreline seepages, in contrast, represent a potentially lethal area to juvenile salmonids regardless of any extent of fish avoidance or of existing river temperature and discharge. These seepage areas are unique to the Hanford site, and are now greatly reduced after reactor closures. (The BC reactor was closed in the spring of 1969.) Shoreline discharges of unmodified reactor effluents should be avoided at any future nuclear power facilities constructed on the Columbia River and other streams utilized by cold-adapted salmonids.

In any situation where heated effluents fail in the range of lethal temperatures and mortalities of fish can occur, there is reason for concern. Our livebox drifts have demonstrated that this does not necessarily mean that the risk of a lethal thermal dose is excessive, but only that losses may occur under certain biological and environmental conditions. We have attempted to clarify the conditions prevailing in the central Columbia River in 1968 and 1969.

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Figure 1. Location of midriver plumes and shoreline discharges of heated effluents in the central Columbia River at Hanford, Washington where experimental drifts of young salmonids were conducted in 1968 and 1969.

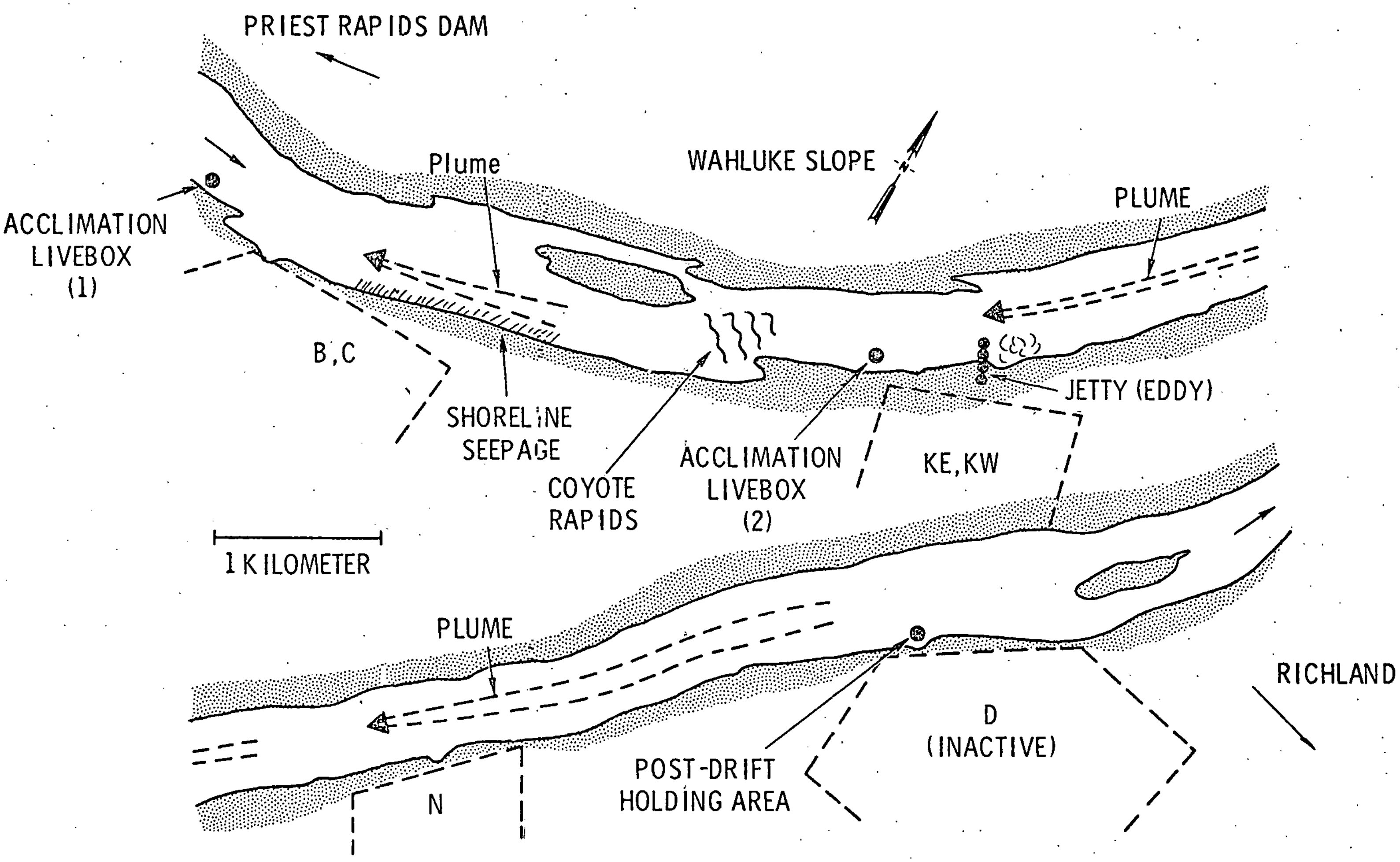

PRIEST RAPIDS DAM
Plume
WAHLUKE SLOPE
PLUME
ACCLIMATION LIVEBOX (1)
B,C
SHORELINE SEEPAGE
COYOTE RAPIDS
ACCLIMATION LIVEBOX (2)
JETTY (EDDY)
KE,KW
1 KILOMETER
PLUME
RICHLAND
D (INACTIVE)
POST-DRIFT HOLDING AREA
N

Figure 2. Mean weekly water temperatures in the central Columbia River at Priest Rapids Dam (above Hanford) and Richland (below Hanford) plus discharge volumes at Priest Rapids in 1969.

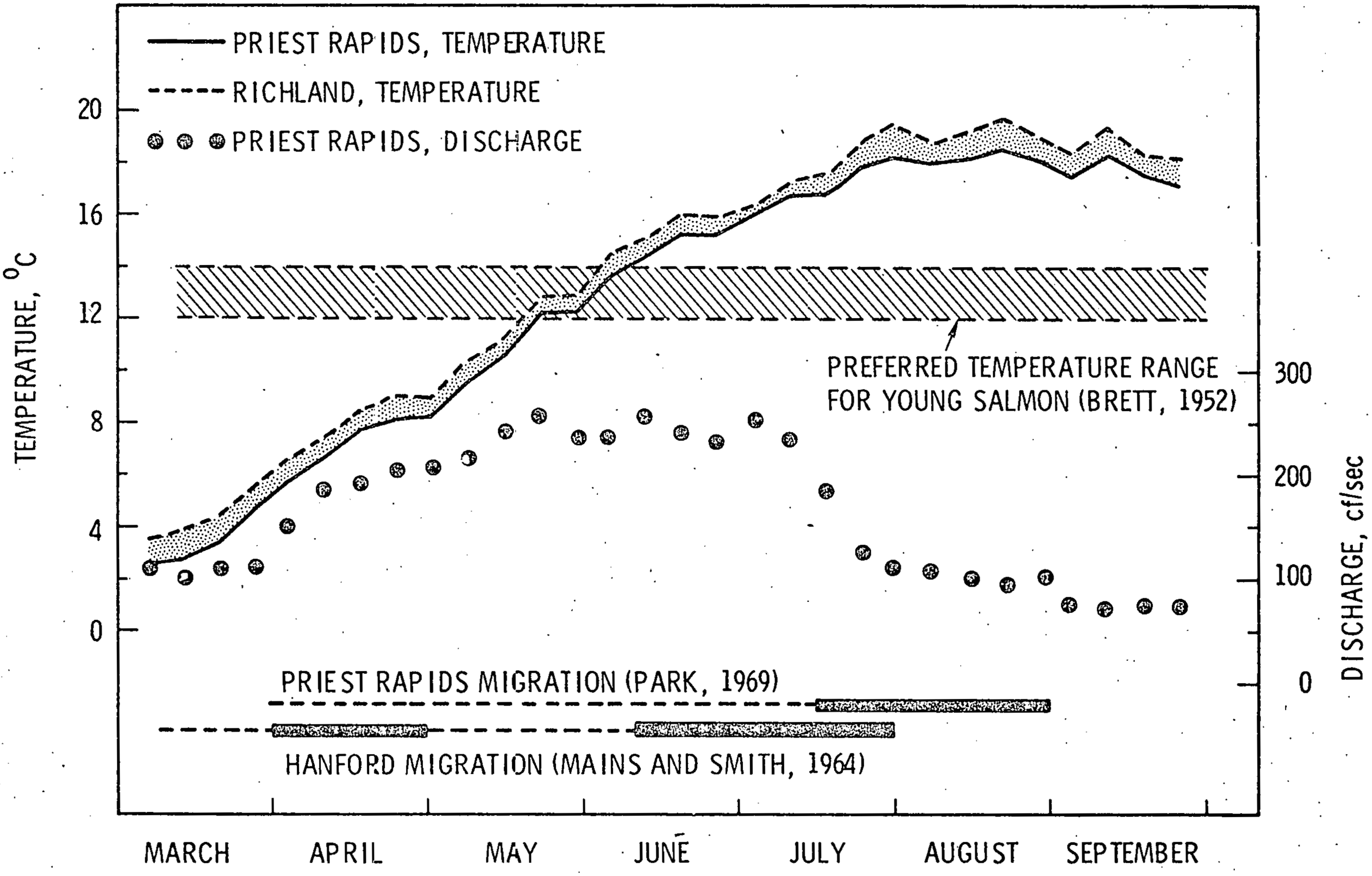
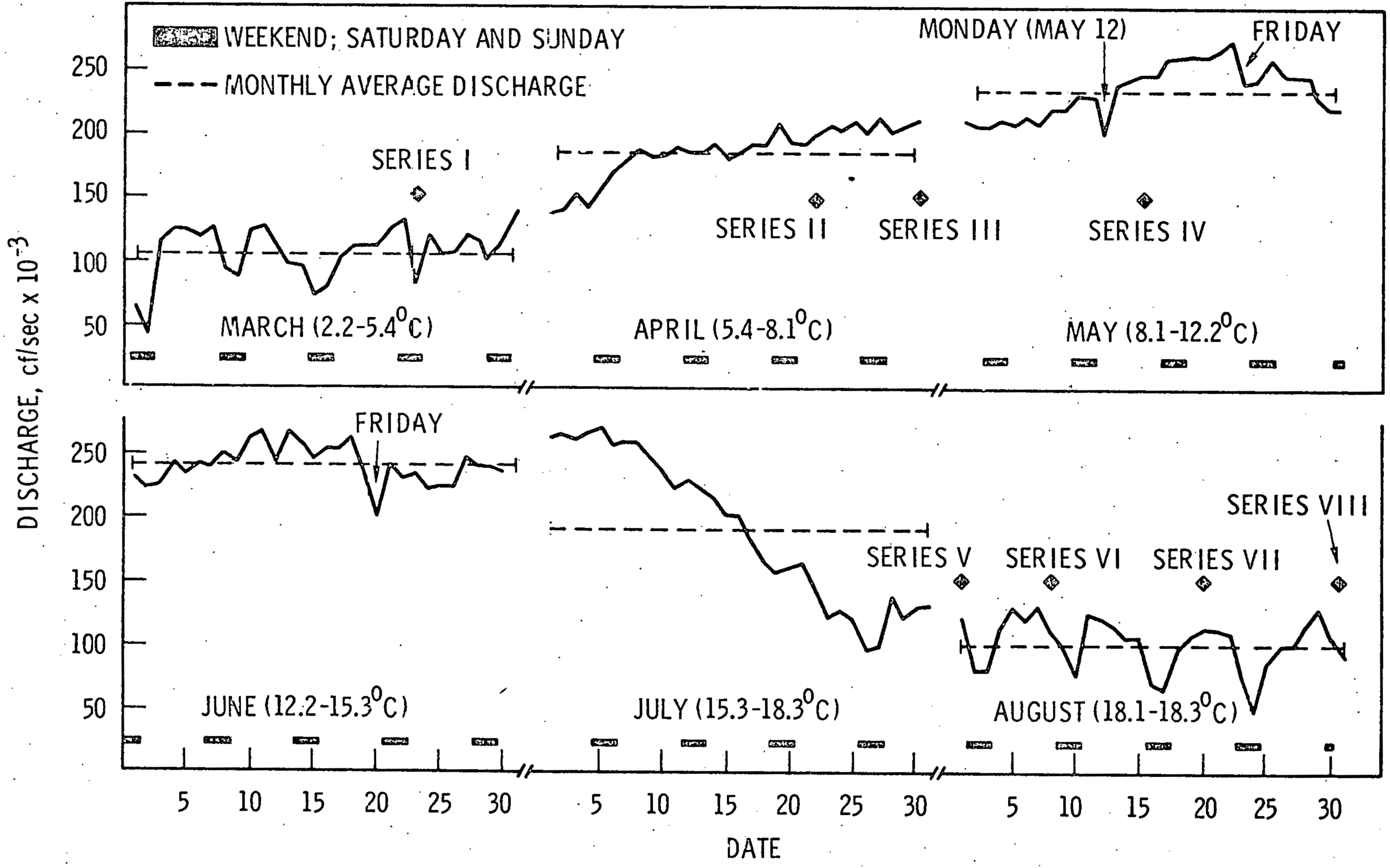

PRIEST RAPIDS, TEMPERATURE
RICHLAND, TEMPERATURE
PRIEST RAPIDS, DISCHARGE
TEMPERATURE, °C
20
16
12
8
4
0
PREFERRED TEMPERATURE RANGE FOR YOUNG SALMON (BRETT, 1952)
300
200
100
0
DISCHARGE, cf/sec
PRIEST RAPIDS MIGRATION (PARK, 1969)
HANFORD MIGRATION (MAINS AND SMITH, 1964)
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER

Figure 3. Mean daily discharges of the Columbia River, March through August 1969, at Priest Rapids Dam in relation to mean monthly temperatures and operational dates of the experimental drifts.



▨ WEEKEND; SATURDAY AND SUNDAY
- - - MONTHLY AVERAGE DISCHARGE
MONDAY (MAY 12)
FRIDAY
SERIES I
SERIES II
SERIES III
SERIES IV
MARCH (2.2-5.4°C)
APRIL (5.4-8.1°C)
MAY (8.1-12.2°C)
FRIDAY
SERIES V
SERIES VI
SERIES VII
SERIES VIII
JUNE (12.2-15.3°C)
JULY (15.3-18.3°C)
AUGUST (18.1-18.3°C)
DISCHARGE, cf/sec x 10^-3
250
200
150
100
50
5
10
15
20
25
30
DATE

Figure 4. Maximum thermal exposures of juvenile salmonids during livebox drifts through effluent discharges at Hanford in 1968. (Arrows point to drifts where significant mortality occurred, i.e. the majority of the fish died.)

Fig 1

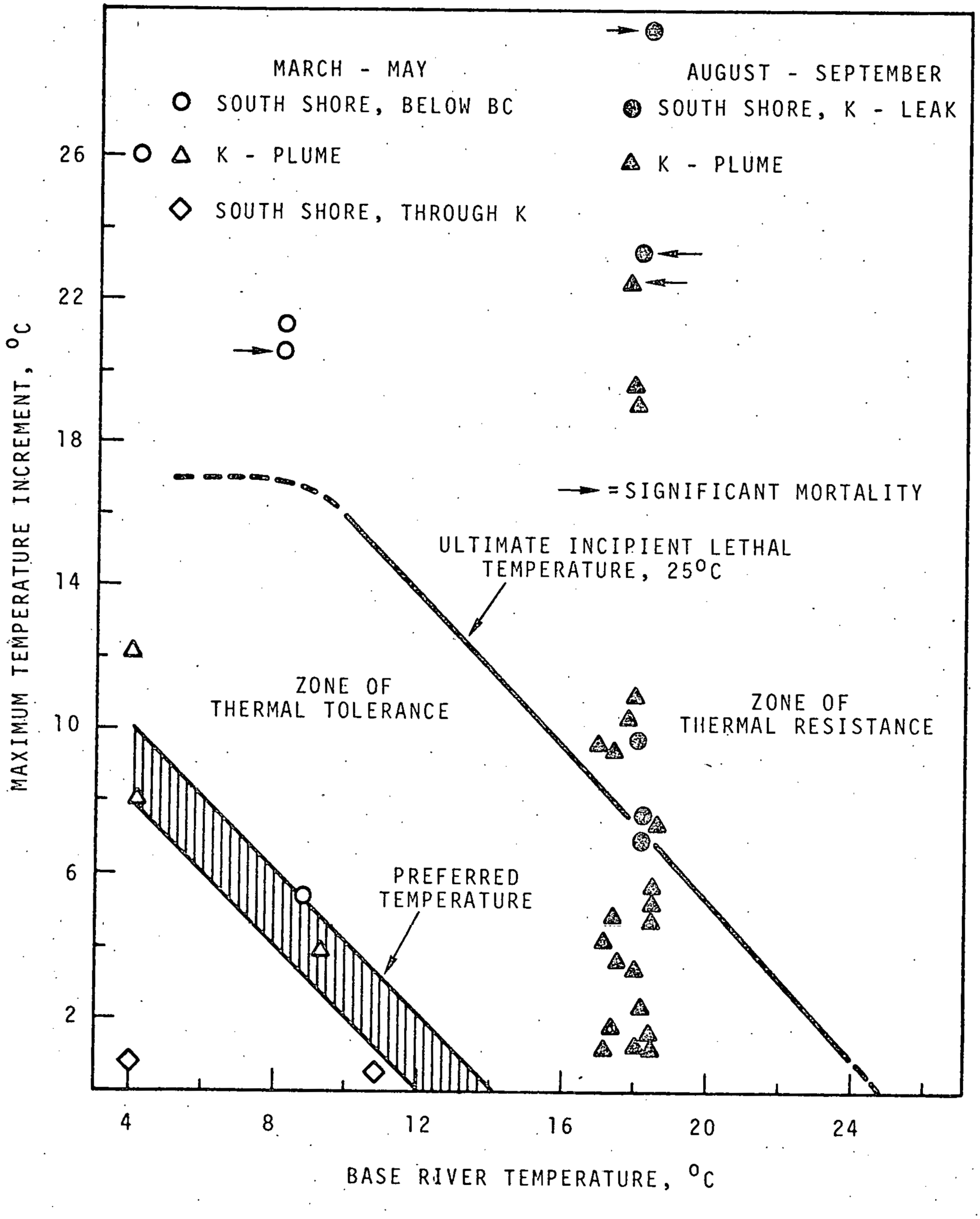

MARCH - MAY
SOUTH SHORE, BELOW BC
K - PLUME
SOUTH SHORE, THROUGH K
AUGUST - SEPTEMBER
SOUTH SHORE, K - LEAK
K - PLUME
= SIGNIFICANT MORTALITY
ULTIMATE INCIPIENT LETHAL TEMPERATURE, 25°C
ZONE OF THERMAL TOLERANCE
ZONE OF THERMAL RESISTANCE
PREFERRED TEMPERATURE
MAXIMUM TEMPERATURE INCREMENT, °C
26
22
18
14
10
6
2
BASE RIVER TEMPERATURE, °C
4
8
12
16
20
24

Figure 5. Maximum thermal exposures of juvenile salmonids during livebox drifts through effluent discharges at Hanford in 1969. (Arrows point to drifts where significant mortality occurred, i.e. the majority of fish died).

Fig. 5

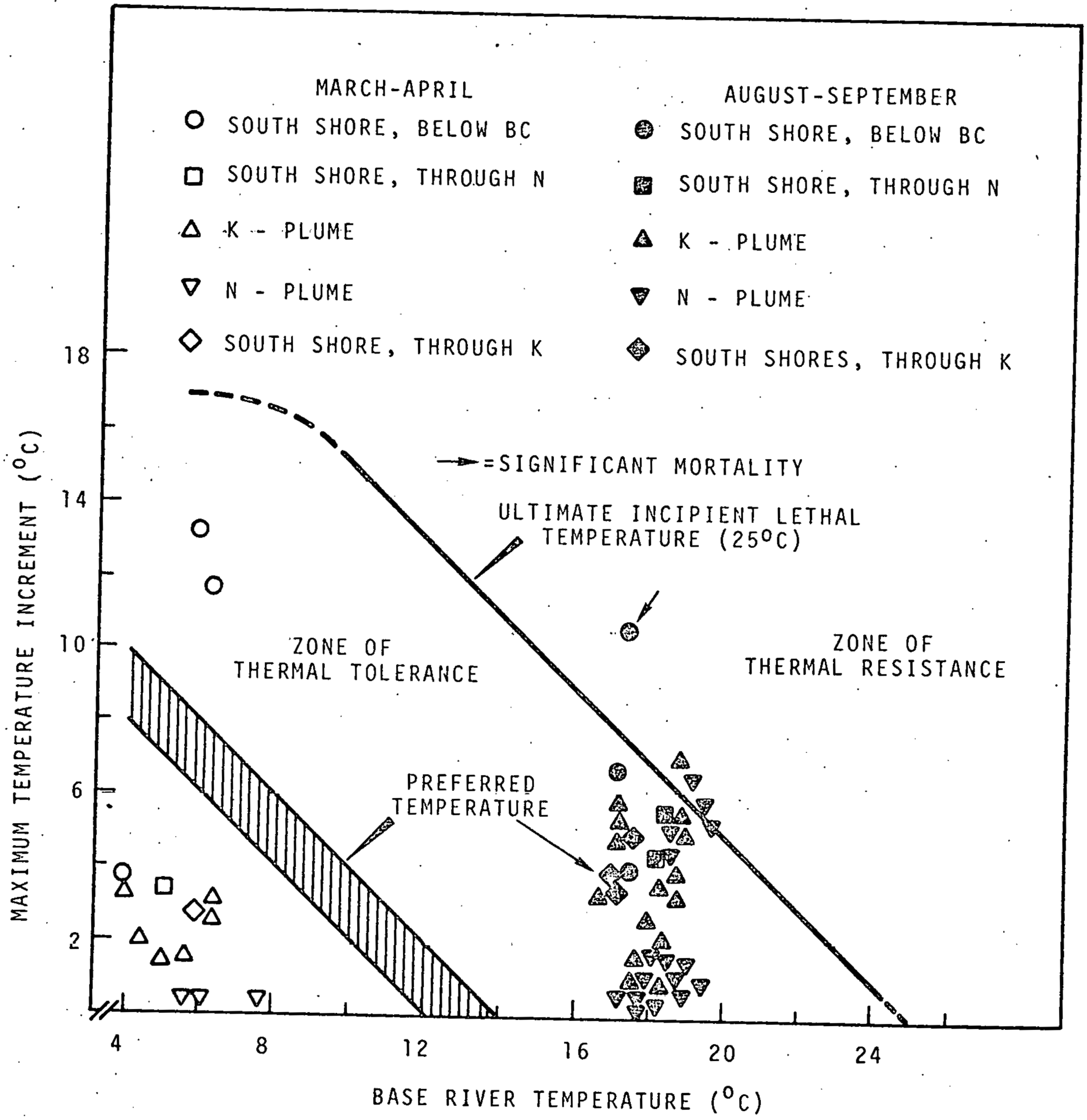
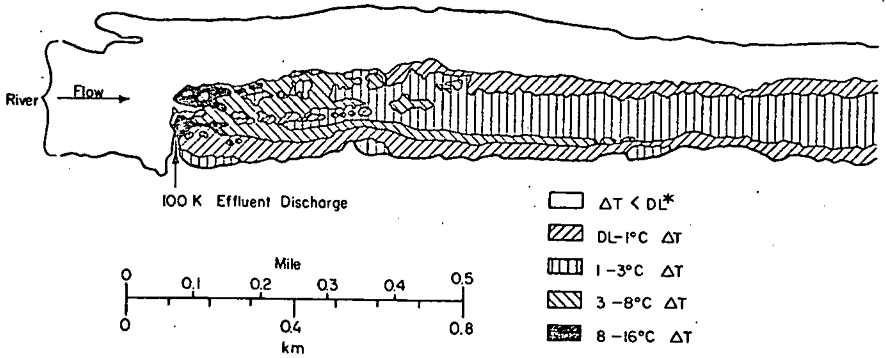

MARCH-APRIL
○ SOUTH SHORE, BELOW BC
□ SOUTH SHORE, THROUGH N
△ K - PLUME
▽ N - PLUME
◇ SOUTH SHORE, THROUGH K
AUGUST-SEPTEMBER
● SOUTH SHORE, BELOW BC
■ SOUTH SHORE, THROUGH N
▲ K - PLUME
▼ N - PLUME
◆ SOUTH SHORES, THROUGH K
→ =SIGNIFICANT MORTALITY
ULTIMATE INCIPIENT LETHAL TEMPERATURE (25°C)
ZONE OF THERMAL TOLERANCE
ZONE OF THERMAL RESISTANCE
PREFERRED TEMPERATURE
MAXIMUM TEMPERATURE INCREMENT (°C)
18
14
10
6
2
4
8
12
16
20
24
BASE RIVER TEMPERATURE (°C)

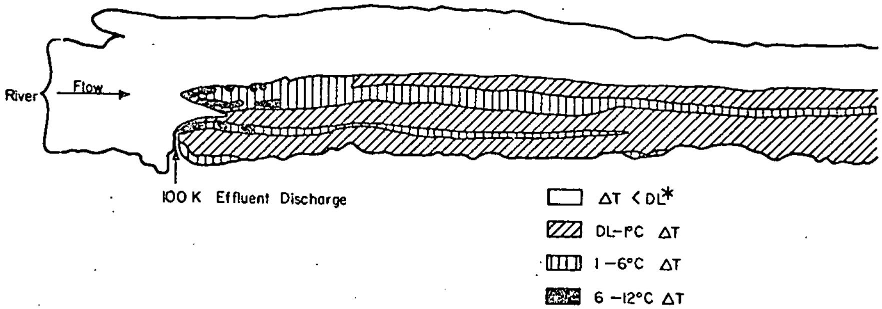
Figure 6. Columbia River surface temperature patterns at the K reactor plume under three river discharges: (A) 41,000, (B) 80,000 and (C) 110,000 ft^3/sec. *DL: The detection limit of aerial infra-red imaging system is about 0.5° C. (From Jaske, Templeton, and Coutant, 1970).

Fig. 6

A: 41000 ft^3/sec flow



B: 80000 ft^3/sec flow



C: 110000 ft^3/sec flow

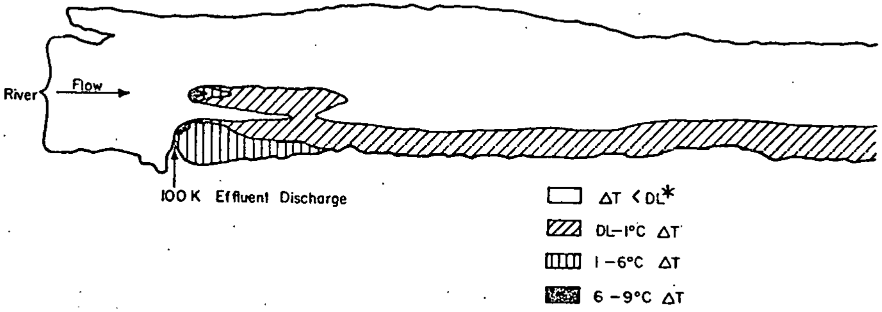
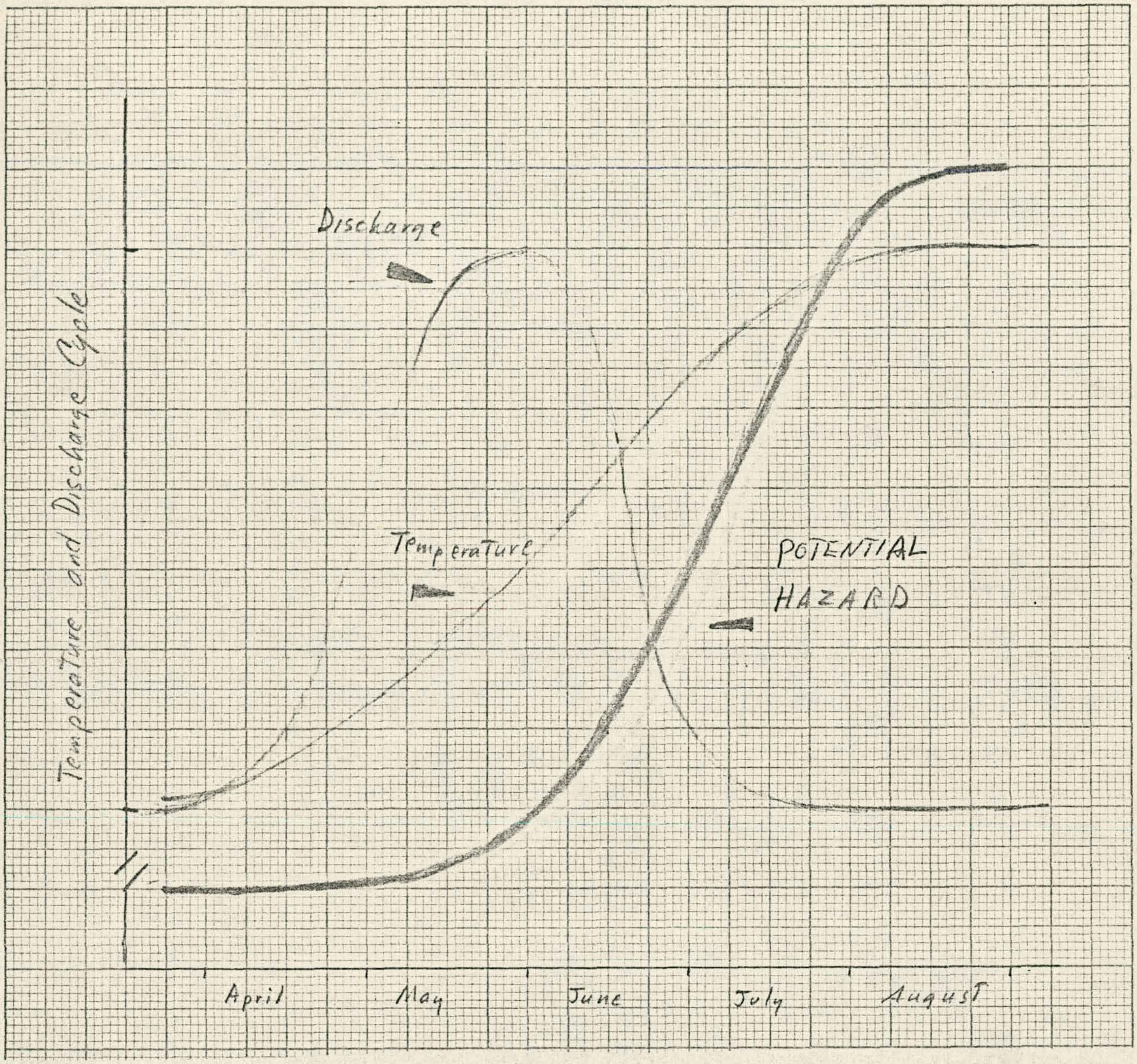


Figure 7. Diagrammatic presentation of the potential thermal hazard to migrating juvenile salmonids in relation to the annual temperature and discharge cycle in the central Columbia River.

Fig. 7


Discharge
Temperature
POTENTIAL
HAZARD
Temperature and Discharge Cycle
April
May
June
July
August