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TEMPERATURE, TIMING AND SEAWARD MIGRATION OF JUVENILE
CHINOOK SALMON FROM THE CENTRAL COLUMBIA RIVER¹

C. D. Becker

Ecosystems Department
Battelle Memorial Institute
Pacific Northwest Laboratories
Richland, Washington 99352

ABSTRACT

A sizeable population of adult chinook salmon now spawns each fall in the Hanford environs of the central Columbia River. This population has acquired significance because most prime spawning areas in the mainstem Columbia have been inundated by hydroelectric development. Studies conducted in 1969 show that the progeny of the Hanford population migrates seaward from April to July in the ancient pattern that correlates with low water temperatures and high discharge volumes. In contrast, the passage of juvenile chinooks which now issue from upriver reaches is known to be delayed until July and August when temperatures and discharge volumes are presumably less favorable.

Temperatures in the central Columbia are modified by the discharge of heated effluent from nuclear reactors at Hanford. Temperature patterns above and below Hanford, and discharge volumes for 1968 and 1969, are figured. The relationship of temperature to the natural and delayed out-migration of juvenile chinooks is discussed in light of two criteria: preferred temperatures of 12-14 °C and an upper incipient lethal limit

¹This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830.

of 25.1 °C (from Brett, 1952). Maximum temperatures in the central Columbia during late summer rarely exceed 22 °C, and have never been recorded as approaching 25 °C. With other, more extensive environmental changes occurring throughout the ecosystem, present temperature levels are recognized as but one factor affecting the survival of young salmon.

INTRODUCTION

Routine operation of nuclear reactors on the U. S. Atomic Energy Commission's Hanford Reservation above Richland, Washington involves the release of heated water into the central Columbia River. Although these reactors have been operating for over two decades, public and professional concern has only recently focused on potential effects of thermal loading on salmonid resources throughout the vast Columbia system. This concern has been prompted largely by the proposed siting of additional reactors on the Columbia and at various locations on other streams inhabited by salmonids in the Pacific Northwest.

The AEC is cognizant of the complex problems imposed by heated reactor discharges in its environmental research program at Hanford. One aspect of this program deals with the bionomics of young chinook salmon (Oncorhynchus tshawytscha) originating in the central Columbia River. The relationship between ambient water temperatures and the timing of the annual seaward migration is explored herein.

THE HANFORD POPULATION

Construction of hydroelectric dams on the Columbia River has now inundated hundreds of miles of spawning areas formerly used by adult

chinook salmon (Fulton, 1968). After completion of the John Day Dam below Arlington, Oregon and the Wells Dam above Chelan, Washington in 1968, only one section of the main channel remains a free-flowing environment. This unaltered section extends from Richland some 90 km upriver to Priest Rapids Dam, and falls primarily within the boundaries of the Hanford Reservation (Figure 1).

Substantial numbers of adult fall chinooks now spawn in the Hanford area. This population, with a 21-year average of but 900 redds, increased to 3270 redds in 1967 and 3560 redds in 1968 (determined by aerial survey); its recent development is partially due to the "barrier effect" imposed by Priest Rapids Dam following construction in 1960 (Watson, 1968, 1969). In recognition that energy reserves of adult salmon are finite as they leave the sea, and that these reserves are reduced by each existing dam the fish surmount, the "barrier effect" of dams sited in the lower Columbia may also contribute to the increase of the Hanford population.

The Hanford spawners presumably originated, to a large extent, from various stocks or races formerly spawning elsewhere in the Columbia River. Due to recent inundation of prime spawning areas, this population is assumed to be a heterogenous mixture of genetic strains which lacks distinct genotype or phenotypic characteristics providing rigid ties with the Hanford environs. It is notable that a portion of this population successfully spawns each fall below the mixing zones of the heated reactor discharges (Watson, 1968, 1969).

The numbers of young chinooks produced in tributaries, hatcheries, and spawning channels above Priest Rapids Dam, in comparison with production in the Snake River, are now relatively low. From 1965-1967 studies

at Ice Harbor Dam on the lower Snake and at Priest Rapids, Raymond (1968) estimated that 90% of the juvenile fish passing seaward issued from the Snake. Raymond's data, however, do not include progeny of fall chinooks spawning at Hanford. On the basis of more than 3000 redds, this population has acquired considerable biological significance in recent years. But its contribution to the total seaward migration has never been measured.

SEAWARD MIGRATION TIMING

Early data on timing of the seaward migration from the central Columbia River are provided by Mains and Smith (1964), whose studies were conducted in 1955 when only two major upriver dams were completed, Rock Island (1933) and Grand Coulee (1938). Seaward movement extended from early March to the end of July in 1955 and consisted of two distinct periods, one in March and April and the other in June and July. The first provided 76% of the total emigration and consisted entirely of fry, while the second provided 24% and consisted largely of "fingerlings." No juvenile chinooks were available in August.

Data provided by Park (1969) from Priest Rapids Dam in 1965 and 1966 demonstrate that the main movement of young chinooks from the upper Columbia (excluding Hanford) now occurs from middle to late summer, with a dominant peak in August (60% of all fish in 1965, 40% in 1966). Changes in the upriver environment from the construction of dams and filling of reservoirs were considered by Park to be responsible for the delay. During the intervening years since 1955, five dams were constructed above Hanford: Priest Rapids (1960), Rocky Reach (1961), Wanapum (1963), Chief

Joseph (1955), and recently Wells (1968). In effect, the upper Columbia has been modified into a consecutive series of impoundments that, including massive Lake Roosevelt behind Grand Coulee Dam, extends beyond the Canadian border.

In 1969, Battelle-Northwest biologists collected young chinooks for analysis of food organisms and feeding activity at Hanford. Seining operations were conducted weekly at established stations from March through August. The resulting data on the migration timing of progeny produced by Hanford spawners, although not quantitative, agree essentially with the 1955 data of Mains and Smith (1964). A few fry appeared in the shoreline habitats as early as mid-March, but fish were not abundant until the second week of April. Emergent fry, retaining a visible portion of the yolk sac, ranged from 34-40 mm (fork length). Population levels remained relatively high until mid-June and declined rapidly during July. No fish were obtained in August.

Basic statistics on the sizes of juvenile chinooks are given in Figure 2. The slow increase of minimum size values show that the fry emerge from the gravel over an extended period, from March to June. The increase in maximum size values in June and July suggests rapid growth under favorable environmental conditions. Analysis of length-frequency distributions (unpublished data) indicates that the shoreline feeding population fluctuated weekly in dynamic equilibrium to recruitment and outmigration. Maximum lengths of 70-85 mm were attained in July, although relatively few fish were still available at this time. Presumably many of the late-run "fingerlings" (modal size of 85-90 mm) observed by Mains and Smith (1964), who did not examine scales for winter annuli, were

advanced juveniles of the 0-age-group (originating from distant upriver areas) rather than over-wintering, 1-age-group fish.

Clearly, an ecological distinction now exists between young chinooks produced in the free-flowing Hanford section and those passing seaward from impounded sections of the Columbia River above. The main differentiating feature is migration timing. Juveniles produced at Hanford retain the historical pattern detected 14 years ago by Mains and Smith (1964), whereas upriver juveniles pass through the central Columbia after considerable delay (Park, 1969).

In 1969, the upriver juveniles again passed Priest Rapids Dam at an abnormally late date (D. L. Park, pers. comm.). Our seining indicated that these fish did not linger in the Hanford area, but passed directly into the forebay of McNary Dam.

TEMPERATURE PATTERNS IN THE CENTRAL COLUMBIA

Water temperatures in the central Columbia fluctuate annually in response to atmospheric conditions and river discharge volumes. Temperatures are generally lowest in January and February, then rise and peak during August and September (Sylvester, 1959; Jaske and Goble, 1967). The establishment of a reservoir complex on the upper Columbia has caused little change in average mean temperatures of the river, but tends to decrease its annual variance and to delay the timing of maximum and minimum temperatures. The Columbia system of dams, with the exception of Grand Coulee, is a system where daily discharges are a significant fraction of reservoir capacity, which permits little effective stratification (Jaske and Goble, 1967). For example, the average temperature at Priest

Rapids Dam in 1965 was 10.4 °C, while the maximum was but 18.0, the minimum 3.2, and the variance 14.8 (Jaske and Goble, 1967).

Temperatures at Richland are sustained above those at Priest Rapids due to the input of heated water from the Hanford reactors, and also from natural heating at points between². However, river temperatures as modified by heated effluent are affected not only by effluent volumes, but also by prevailing, largely seasonal temperatures and discharge volumes in the river proper. These relationships are illustrated in Figure 3. The spring rise in temperature in 1968 was retarded by suddenly increased discharges during June due to the onset of flood waters. In 1969, flood conditions occurred about 6 weeks earlier and high discharges were sustained for three months, while retardation of the spring rise in temperature was scarcely evident. In both years, mean weekly water temperatures peaked in late July, August and early September with maximum daily temperatures briefly reaching 19.1 and 19.7 in 1968 and 1969, respectively, at Priest Rapids, and 19.7 and 20.6 at Richland.

TEMPERATURE AND EMIGRATION

The thermal requirements of juveniles of the five Pacific salmon (genus Oncorhynchus) were evaluated by Brett (1952) in classic laboratory experiments. He found that preferred temperatures fell between 12-14 °C, from numerous trials with fish acclimated to temperatures ranging from 5 to 24 °C. The juveniles of all species avoided temperatures above 15 °C but would penetrate this strata under feeding stimuli. Brett established the ultimate upper lethal temperatures, where 50% of the test

²Unpublished data taken during reactor shutdown, July and August 1966, show a significant increase in river temperature between Priest Rapids and Richland solely on the basis of heat increment from natural sources.

fish died after one week of exposure, at 23.8 to 25.1 °C, depending on species. Juvenile chinooks and cohos (O. kisutch) had the greatest thermal resistance. On the basis of intensive artificial propagation, Burrows (1963) established broader limits, 10.0-15.6 °C (50-60 °F), as the range for maximum productivity of fingerling salmon.

Projection of these data to Figure 3 demonstrate that temperatures in the central Columbia are sustained well below preferred levels in March and April during the initial emergence of fry. Temperatures enter the preferred range, where conditions are presumably near optimum for all life processes, in May and June. In July and August, temperatures rise into the zone of thermal tolerance where normal life functions are modified in reaction to higher heat regimes. Simultaneously begins the summer period of low flow.

Limited data are available on environmental conditions during out-migration in earlier years. Mains and Smith (1964) recorded temperatures of 4.4 to 15.6 °C (40-60 °F) during the movement of juvenile chinooks from the Snake River in 1954 and 1955, and from the central Columbia in 1955. The first spring freshet in March and early April triggered the initial departures of fingerlings from the Snake, and the emigration peaked in mid-April about one month ahead of maximum daily discharges. Neither temperature or discharges were correlated with initial fry movement on the central Columbia in 1955 (Mains and Smith, 1964), but the first major increase in flow during June initiated the movement of "fingerlings." (Spring flows were delayed in 1955 from storage of water in Grand Coulee pool.)

At Hanford, in 1969, the first fry appeared in shoreline zones in March when midriver temperatures were cold, at 3-5 °C. Population abundance peaked from mid-April to mid-June when temperatures extended from 7-15 °C and discharge volumes reached a seasonal maximum. In July,

with inshore populations greatly reduced, temperatures climbed to 17-19 °C and discharge volumes dropped (Figure 3). Temperatures in the inshore feeding areas, however, were consistently elevated a few degrees above those in midstream due to reduced currents and solar radiation. In effect, by the end of July, the summer warming of the river and reduced flows tend to "flush" the remaining juvenile salmon from the Hanford section.

Parks's (1969) data show that the bulk of the seaward migrants originating above Hanford now pass Priest Rapids in July and August. Environmental conditions are such that temperatures in the central Columbia at this time are near the annual maximum and discharge volumes are decreasing to near the annual minimum (Figure 3). The ecology of these juveniles as they move towards the sea may, therefore, differ substantially from that of fish originating at Hanford.

DISCUSSION

The natural outmigration of young chinooks is a phenomenon that involves successive correlation in time between emergence, favorable river temperatures and discharges, and physiological adjustment to seaward movement. In the view of Thompson (1959), salmon (i.e., O. nerka) historically pass through a chain of favorable environments connected with a definite season in time and place in such a way to provide for maximum survival rates. Young chinooks in the Columbia system must adhere to links in a similar chain in which, however, the emigration timing is but one phase vital to completion of their life cycle.

Juvenile chinooks leaving the central Columbia River may now be separated into two components on the basis of migration pattern. Those

produced in the free-flowing Hanford environs retain their natural timing, whereas those originating above Hanford (tributaries, hatcheries and spawning channels) are delayed 1 to 2 months. This delay, presumably due to recent augmentation of the reservoir complex, exposes the upriver juveniles to temperatures above and river flows below what would normally be encountered when passing through the Hanford area.

Park (1969) postulated that juvenile chinooks find environmental conditions in the Columbia River most favorable for survival in the spring, whereas fish passing through impounded areas during July and August encounter conditions that are far from optimum. The relationship of migration timing to seasonal changes in ambient water temperatures, and also to river discharge volume, requires closer scrutiny.

Examination of Figure 3 shows that temperatures of the mixed water (reactor plus river) at Richland adhere closely to, but persist somewhat above, that of the unmixed water entering Hanford. In March and April, when the first Hanford fry emerge from the gravel, river temperatures are well below the preferred level for juvenile salmon. In view of Brett's (1952) conclusion that young salmon are generally intolerant of extreme low temperatures, it is logical that the addition of heat by the Hanford discharges during early spring is not harmful and may actually be beneficial to emergent fry.

Records at Priest Rapids and Richland show that temperatures reach preferred levels (12-14 °C) for juvenile salmon during May and June, but extend above these levels in late June. The most critical period for survival occurs in July, August and September when temperatures enter the zone of thermal tolerance, above preferred but still well

below the lethal limit (25.1 °C) established by Brett (1952). Data assembled at Hanford reveal that temperatures in the central Columbia rarely reach 22 °C, and have never been recorded as approaching 25 °C. Any effects, actual or hypothetical, resulting from maximum summer temperatures in the central Columbia would, therefore, likely be manifest only at sub-acute levels. Furthermore, such thermal effects would operate more selectively upon young chinooks originating above Priest Rapids because of their later passage.

Environmental modifications on the lower Columbia River from the construction of dams and filling of reservoirs may obscure the distinct migration patterns manifest in the two populations of young chinooks passing from the Hanford area and tend to equalize any differences in survival rates. The reservoir complex below Hanford also retards seaward migration (Raymond, 1968, 1969) and theoretically exposes all juveniles (plus those originating from the Snake River) to detrimental factors associated with delay. These factors include late season temperatures and the unavoidable passage through impoundments and over dams under low flow conditions. Park's (1969) statement that environmental changes "could eventually jeopardize" the existence of chinook salmon in the upper Columbia River is conservative. Extensive changes have already occurred. Increments to the thermal regimen of the Columbia River from present Hanford operations are but one factor, perhaps a minor one as indicated by temperature records (Figure 3), affecting the survival of these fish.

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FIGURE 1. THE HANFORD ENVIRONS OF THE CENTRAL COLUMBIA RIVER

FIGURE 2. MEAN, STANDARD DEVIATION AND RANGE OF CHINOOK SALMON JUVENILES TAKEN IN THE HANFORD ENVIRONS, MARCH-JULY, 1969

FIGURE 3. MEAN WEEKLY WATER TEMPERATURES IN THE COLUMBIA RIVER AT PRIEST RAPIDS AND AT RICHLAND, PLUS DISCHARGES AT PRIEST RAPIDS, FEBRUARY-NOVEMBER, 1968 AND 1969 (PREFERRED TEMPERATURE AT 12-14°C FOR JUVENILE SALMON FROM BRETT, 1952)