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FEEDING BIONOMICS OF JUVENILE CHINOOK SALMON
RELATIVE TO THERMAL DISCHARGES IN THE CENTRAL COLUMBIA RIVER

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Running Head: Feeding Bionomics of Juvenile Chinook

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Abstract

Juvenile chinook salmon (Oncorhynchus tshawytscha) in the Hanford environs of the central Columbia River, Washington consumed almost entirely adult and larval stages of aquatic insects. The food organisms were dominated by midges (Diptera: Tendipedidae); by numbers, adult midges provided 64 and 58% of the diet and larval midges 17 and 18% of the diet, in 1968 and 1969, respectively. The families Hydropsychidae (Trichoptera), Notonectidae (Hemiptera) and Hypogastruridae (Collembola) were of secondary importance. Small fry fed almost exclusively on the small tendipedids. Over 95% of all food organisms originated within the river ecosystem. The distinctive features of food and feeding activity were fourfold: first, relatively few insect groups were utilized; second, the fish depended on drifting, floating, or swimming organisms; third, they visually selected living prey moving in or on the water; and fourth, they were habitat opportunists to a high degree.

The 1969 data were studied to reveal possible thermal effects of heated discharges from plutonium production reactors at Hanford on food and growth parameters. All data were characterized by considerable variation between and within stations. No discernable effects between coldwater and warmwater stations were revealed by analyses of: 1) groups of food organisms utilized, 2) food and feeding activity, 3) numbers of insects consumed, 4) seasonal increases in fish length, 5) fish length-weight

relationships, 6) fish coefficients of condition, and 7) stomach biomass. The lack of detectable thermal effects was apparently due to the fact that the main effluent plumes discharge in midstream and the effluents are well mixed before reaching inshore feeding areas. The transient nature of fish groups at each station, influenced by changes in regulated river flows, and the availability of food organisms in the river drift were ecological factors affecting critical thermal evaluation in situ.

FEEDING BIONOMICS OF JUVENILE CHINOOK SALMON RELATIVE TO THERMAL DISCHARGES IN THE CENTRAL COLUMBIA RIVER (1)

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INTRODUCTION

Studies on thermal effects in aquatic environments and requirements for optimal temperatures for aquatic organisms have increased during the last decade due to national awareness of the omnipotent changes in water quality and of the eminent need for environmental preservation. Nuclear reactors for plutonium production have discharged heated effluents into the central Columbia River at Hanford, Washington over the past 25 years. Concern over actual and potential effects of thermal increments from the Hanford operations has stimulated an active program of intergrated laboratory and field investigations sponsored by the U.S. Atomic Energy Commission and conducted by the Pacific Northwest Laboratories of Battelle Memorial Institute.

Field studies on the relationship of thermal discharges to the food and feeding of juvenile chinook salmon (Oncorhynchus tshawytscha) were initiated in 1968 and expanded in 1969. The objectives of this program were to (1) evaluate the food composition and feeding activity of the fish during their temporary sojourn preceding seaward migration and (2) determine if heated reactor effluents directly or indirectly influence their welfare. The program was

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

prompted by the possibility that disposal of heated effluents might be either detrimental to the food organisms upon which juvenile salmon depend or effect their feeding activity and subsequent growth.

Initial studies in 1968 proved rewarding and provided data not only on food organisms consumed (Becker, 1969; 1970a) but also on the basic autecology of juvenile chinook in the Hanford area (Becker, 1970b). An expanded sampling program was conducted in 1969 to provide a firmer basis for evaluating potential thermal effects. The results of this investigation are combined with previous work and detailed herein.

SOME EFFECTS OF TEMPERATURE ON FEEDING AND GROWTH OF SALMONIDS

Poikilothermous vertebrates and invertebrates in aquatic environments are highly temperature dependent. Populations are regulated by temperatures acting upon various phases of their life cycles, particularly upon growth and reproduction. The precise interactions and ecological limits of multifacet thermal effects remain unknown for the majority of species. Some effects of temperature on feeding and growth of salmonids, culled from the literature, are detailed here.

Preferred temperatures for juvenile salmonids, where conditions are presumably near optimum for feeding and growth, were established in laboratory at 12-14° C by Brett (1952) and the range for maximum production of fingerlings in hatcheries (with unlimited supply of

artificial food) was listed as 10-15.6° C (50-60° C) by Burrows (1963). Brett (1952) also gave 25.1° C as the upper incipient lethal level (where 50% of the fish died after one week of exposure) for juvenile chinook. However, it is now known that the upper lethal limit of fish in nature may be somewhat less than determined under controlled laboratory conditions (Ferguson, 1958); this appears to be true for juvenile chinook in the Columbia. Fish are sensitive to small temperature changes (0.05° C) and tend to avoid areas heated in excess of their thermal preferenda (Alabaster, 1963; Bardach and Bjorklund, 1957; Bull, 1936). Yet young salmonids will enter thermal gradients approaching the lethal level in response to feeding stimuli under laboratory conditions (Brett, 1952).

The diverse effects of temperature on activity and metabolism of fishes have been summarized by Brett (1956), Fry (1964, 1967), Mihursky and Kennedy (1967) and others. Allen (1941), in studies of young Atlantic salmon (Salmo salar), noted that temperatures apparently regulate both the amount of feeding and growth. Metabolic rates necessary to maintain an organism generally increase with a rise in temperature to a point below the critical thermal maximum.^[1] Of immediate interest for evaluation of thermal effects on food and feeding of fish, there is a point in the upper range of thermal tolerance but below the lethal level where feeding is restricted. Fingerling sockeye salmon (O. nerka) cease eating under experimental conditions when temperature increase from 17.2 to 25.6° C (Donaldson

[1] The rate of metabolism is accelerated by heat in accordance with the Van't Hoff principle that the rate of chemical reaction increases with rising temperature. For example, Brett (1965) found that the basic metabolic rate of juvenile sockeye salmon was six times higher at 24° C than at 5° C.

and Foster, 1941), and weekly consumption of minnows by brook trout (Salvelinus fontinalis) decreases at temperatures from 17.2 to 21° C (Baldwin, 1957). For every 10° rise in temperature between 40° F (4.4° C) and 60° F (15.6° C), food consumption of juvenile chinook increases about 60% (Burrows, 1963).

Digestion, as an index to metabolism, is strongly influenced by increases in water temperature. Digestion of soft-bodied insect larvae by brook trout proceeds more rapidly at 11° C than at 7° C (Hess and Rainwater, 1939). The time required for rainbow trout (Salmo gairdneri) to digest half-gram meals ranges from 70 hours for chitonized insects at 0-0.6° C (32-37° F) to 12 hours for soft-bodied insects at 9.4-11.7° C (49-53° F), according to Reimers (1959). Rates of gastric digestion of dragonfly naiads by bluegill (Lepomis macrochirus) show a major decrease with a temperature drop from only 18.5 to 17.1° C (Windell, 1957). Digestion of food by piscivorous bass (Micropterus salmoides) increases rapidly with an increase in temperature from 5 to 10° C (Molnár and Tölg, 1962).

Ultimately a point is reached at rising temperatures where a fish expends more energy than it replaces, despite a superabundance of food, and weight gain is stabilized or even reduced. Juvenile chinook cultivated at 24° C, even though active and feeding well, display lower growth rates than fish reared at lower temperatures (Brett, 1952). Although food consumption of fish is normally higher at warmer temperatures, the animal is more active and a large proportion of its intake is burned merely in maintaining body

functions. For these reasons, optimum growth of young sockeye (O. nerka) occurs near 15° C, and no growth takes place at about 23° C despite the presence of excess food (Brett, Shelbourn and Shoop, 1970).

The above data, although not inclusive, suggests that there is an optimum temperature for metabolism, as revealed by feeding activity and growth rates, for each species of fish. Furthermore, this temperature may roughly correspond to the "preferred" temperature of individual species. Metabolic rates are reduced at temperatures below this theoretical optimum and increased at temperatures above, both slowing the maximum growth rate. Rainbow trout feed readily at low temperatures, but digestion takes 2-3 times longer at 1.6° C than at 10° C (Reimers, 1957). The time for complete digestion of food pellets by yearling sockeye salmon decreases from 147 hrs at 3° C to 18 hrs at 23° C (Brett and Higgs, 1970). Weight gain of brook trout, based on weight of food consumed, was high at 13° C but low at 9° C and 17° C (Baldwin, 1957). Survival times for juvenile salmonids may be significantly increased at low temperatures if the food supply is limited and fish are starved, as demonstrated for brook trout (Latta, 1969), presumably because of reduced metabolic rates. Starvation may also induce changes in the preferred temperatures of young salmonids. For example, fingerlings rainbow and brook trout select lower temperatures when starved whereas young Atlantic salmon select higher temperatures (Javaid and Anderson, 1967).

Small changes in temperature can be expected to alter responses of young salmon to water currents (Keenleyside and Hoare, 1954), and thus influence feeding activity and food consumption. Young steelhead (Salmo gairdneri) and chinook overwintering in Idaho streams often hide in the substrate when temperatures drop below about 5° C (Chapman and Bjornn, 1969), and presumably reduce their food intake.

METHODS

Young chinooks of the 0-age group were collected by hand and beach seines in the free-flowing Columbia River at stations situated above, below, and in the vicinity of heated reactor discharges at Hanford. The majority of these fish were progeny of adult fall chinook salmon, as defined by Fulton (1968), which spawn below Priest Rapids Dam during October and November.

Collections and stomach analyses were made of 445 fish taken from April 8 to June 28, 1968 and the preliminary results were reported by Becker (1969, 1970a). A more comprehensive sampling program was established in 1969, and stomachs of 769 fish were examined from March 4 to July 29 (Table 1). The sampling span corresponded to the annual period of abundance and migration of juvenile chinook in the central Columbia (Mains and Smith, 1964; Becker, 1970b). All samples were collected between 0900 and 1500 hours and preserved in 10% buffered formalin immediately after capture to stop digestive action. The fish were later measured (fork length) and eviscerated. Since formalin causes limited

shrinkage, all measurements were taken after at least 7 days postpreservation to obtain consistency. Organisms in the stomach contents, primarily insects, were identified individually to the lowest practical category under a dissecting microscope with the aid of appropriate taxonomic keys, classified according to their developmental stage, and enumerated. (Fragmentation, partial digestion, and inadequate representation prohibited identification of a few food organisms.) Insects represented by isolated chitinous head capsules, particularly larval Tendipedidae, were counted as complete organisms whereas fragmented body parts were largely excluded. Methods in 1969 were modified to include data on length-weight relationships of the fish and dried weight of their stomach contents. Fish were individually blotted with absorbent paper to remove excess fluid prior to weighing. After identification and enumeration, the entire stomach content of each fish was placed in a miniature watch glass, air dried at least 24 hours in a controlled atmosphere, and weighed.

Sampling stations in 1968 were inconsistent and fish were collected from various locations depending on the prevailing water level. Six primary stations were established in 1969, three above the Hanford effluent discharges (A, B, C) and three below (D, E, F), and were sampled more or less consistently (Table 1); in this report, these will be designated coldwater stations (CWS) and warmwater stations (WWS), respectively. Supplemental samples were scattered among four secondary stations (W, X, Y, Z). All samples

Table 1. Summary of Stations and Number of Juvenile Chinook examined in 1969 Food Analyses

Date	Number of Chinook Examined										Fish per Date
	"Coldwater" Stations ⁽¹⁾					"Warmwater" Stations ⁽¹⁾					
	A	B	C	W	D	E	F	X	Y	Z	
March 4					19						19
11				14	10						24
25								3			3
April 1					2						2
8			20		20	20	15		5		80
15	10		10		20	10	10	9		7	76
24	10		10		20	10	7				57
29	10	10			20	10	10				60
May 5											0
13	10				20	10	10				50
20	10	10			10	10	10	10			60
27	10	10			10	10	10				50
June 3	10	10			10	10	10				50
10		10			8	10	10	10			48
16	7	10	10		10	10	10				57
24	10	10			4	10	10				44
July 2		3			10	10	10				33
7					10			6			16
15	10		10								20
21	10										10
29							10				10
Fish per Station	107	73	60	14	203	130	132	38	5	7	769
	(Σn ₁ = 254)				(Σn ₂ = 515)						

(1) Cold and warmwater stations were located above and below the reactor discharges, respectively. Coldwater stations A, B and C and warmwater stations D, E, and F were used for analysis and comparison of food habits and growth.

were utilized in identification of food organisms, but only data from the primary stations in 1969 were compared for possible effects of thermal discharges. Station features varied widely because of changing water levels associated with spring runoff (seasonal) and with flow regulation (daily and weekly) at Priest Rapids Dam, above Hanford. Changing water flows, which ranged from about 40,000 to 280,000 ft³/sec over the season, handicapped consistent inter-station sampling. Field records were kept on ambient surface water temperatures and substrate characteristics at each station. Inter-station features were subsequently judged to be of relatively minor importance to the gross ecological picture in comparison with seasonal changes in river temperature and fluctuations in river discharge.

ENVIRONMENTAL CONDITIONS IN THE CENTRAL COLUMBIA

Hydroelectric dams throughout the Columbia River system have, at the present time, inundated many vital spawning areas for adult salmon and lotic feeding areas for juvenile salmon (Fulton, 1968). Only one section of the main river channel remains near its primitive, free-flowing condition. This section extends from Richland, Washington some 93 km upriver to Priest Rapids Dam and falls largely within the confines of the U.S. Atomic Energy Commission's Hanford Reservation where this study was conducted. One result of inundation has been the development of a substantial spawning population of adult chinook in the Hanford environs, which has produced over 3,000

redds each fall since 1966 (Watson, 1970). The progeny of these adults reside in the river during the spring and early summer before migrating seaward (Mains and Smith, 1964; Becker 1970b). Other young salmonids produced in upriver tributaries, hatcheries, and spawning channels pass through the Hanford area on their way to the sea.

River temperatures and discharges are two major physical factors that influence availability of food organisms and feeding activity of juvenile chinook in the central Columbia River. Any study dealing with in situ effects of thermal discharges must recognize these factors, which change annually in a well-defined cycle.

Environmental conditions in the central Columbia during the spring and summer of 1969 are illustrated in Figure 1. Temperature and discharge features are essentially similar from year to year. Thermal levels respond to seasonal variations in atmospheric conditions; they are lowest in January and February, rise during the spring, and peak during August and September. Temperatures at Priest Rapids (above Hanford) are somewhat lower than those at Richland (below Hanford) because of thermal increments from heated discharges at Hanford and, during the summer, of solar radiation in the free-flowing river. From the standpoint of thermal requirements of juvenile chinook, temperatures are well below the thermal preferenda of 12-14° C (Brett, 1952) in March and April when most fry emerge from the gravel. Temperatures enter the preferred range in May and early June, where conditions are presumably

Figure 1. Temperature and flow in the central Columbia River during the spring and summer of 1969, in relation to the presence of juvenile chinook, and their preferred temperature and optimum growth (hatchery production) ranges.

optimum, and are sustained above this level during July and August. Maximum daily temperatures recorded at Priest Rapids and Richland in 1969 were 19.7 and 20.6° C, respectively. These peaks were well below the apparent upper incipient lethal level of 25.1° C (Brett, 1952), although the upper lethal limit of juvenile chinook inhabiting the Columbia River may be somewhat below this level. Temperatures of 20° C and above, regardless of lethal effects, may well be suboptimum for young chinook because of high metabolic requirements and excessive expenditure of energy.

The annual range in river flow volumes through Hanford extends from about 40,000 to 280,000 ft³/sec. Flows are low during the fall and winter, but increase and peak during April, May and June due to the annual runoff of the spring freshet. In 1969, flows increased about 6 weeks earlier than usual because of operational releases at massive Grand Coulee Dam (from Lake Roosevelt) on the upper Columbia. High flows were sustained about three months, decreased sharply in July, and minimum flows were attained in August and September.

The data illustrated in Figure 1 are based on weekly means and fail to adequately reveal the extent of either weekly or daily fluctuations in river discharges that occur from flow regulation at Priest Rapids Dam above Hanford. Such fluctuations are indicated in Figure 2. Generally flows are reduced on weekends and increased during the week in response to consumer demands for hydroelectric power. Similar but less extreme variations are induced

Figure 2. Daily fluctuations in Columbia River flows due to regulation at Priest Rapids Dam (above Hanford) in relation to the seasonal discharge cycle and monthly temperatures, March-August 1969.

daily. During the annual spring spate, river water in excess of reservoir capacity is discharged over spillways at Priest Rapids. Weekly fluctuations during high river flows are less variable than during the summer and winter when a greater need exists to conserve available water in reservoirs. Summer flow regulation on weekends may result in changes of the water level at the sampling stations of up to 5 feet in a 24 hr period.

As indicated in Figure 1, juvenile chinook are present in shoreline areas from late March to mid-July. During this span, the fish hatch and leave the gravel; some are carried downriver while others assemble in shoreline areas for indeterminate periods of feeding and growth before departing seaward. It is theorized that the combination of increasing river temperatures and increasing then decreasing river flows tend to displace most fish lingering at Hanford seaward by the end of July (Becker, 1970b), in combination with the development of the inherited migratory instinct.

FOOD COMPOSITION AND FEEDING ACTIVITY

Food Organisms

A summary of organisms consumed by juvenile chinook in 1968 and 1969 is given in Table 2. Throughout their sojourn in the free-flowing river, the fish fed primarily upon various forms of insects (>95% of their diet) whereas other organisms occurring in the stomach contents were inconsequential. The forms included adult, subadult and larval stages of semiaquatic insects, various developmental

Table 2. Summary of Organisms Consumed by Juvenile Chinook (0-Age Group) in the Hanford Environs of the Central Columbia River. (435 and 769 Fish Examined in 1968 and 1969, Respectively).

Food Organism	1968		1969	
	Number	%	Number	%
INSECTA				
DIPTERA				
<u>Adults</u>				
Tendipedidae ⁽¹⁾	5,973	63.5	11,062	58.2
Dolichopodidae	31	0.3	6	--
Empididae	13	--	4	--
Simuliidae	4	--	52	0.3
Culicidae	0	--	6	--
Ephydriidae	1	--	3	--
Heleidae	0	--	1	--
Stratyomyidae	0	--	1	--
Dixidae	0	--	1	--
Unidentified	82	0.9	193	1.0
<u>Larvae</u>				
Tendipedidae	1,596	17.0	3,450	18.1
Dolichopodidae	18	--	4	--
Empididae	0	--	1	--
Simuliidae	55	0.6	54	0.3
Ephydriidae	1	--	1	--
Heleidae	3	--	0	--
Muscidae	3	--	0	--
Unidentified	7	--	9	--
<u>Pupae</u>				
Tendipedidae	7	--	18	0.1
Tipulidae	5	--	0	--
Heleidae	0	--	2	--
Unidentified	5	--	4	--
TOTAL DIPTERA	7,804	82.9	14,872	78.2

Table 2. (cont'd)

Food Organism	1968		1969	
	Number	%	Number	%
HEMIPTERA				
Notonectidae	248	2.6	918	4.8
Mesoveliidae	34	0.4	2	--
Macroveliidae	1	--	0	--
Corixidae	1	--	1	--
Salidae	4	--	8	--
Hebridae	1	--	0	--
Unidentified	11	--	27	0.1
TOTAL HEMIPTERA	300	3.2	957	5.0
COLEOPTERA				
<u>Adults</u>				
Unidentified	4	--	23	0.1
<u>Larvae</u>				
Dytiscidae	26	0.3	13	--
Noteridae	1	--	0	--
Hydrophilidae	1	--	1	--
Elmidae	0	--	1	--
Ptilodactylidae	1	--	0	--
Unidentified	1	--	16	0.1
TOTAL COLEOPTERA	34	0.4	54	0.3
LEPIDOPTERA				
<u>Adults</u>				
Unidentified ⁽²⁾	3	--	187	1.0
<u>Larvae</u>				
Unidentified ⁽²⁾	0	--	21	0.1

Table 2. (cont'd)

Food Organism	1968		1969	
	Number	%	Number	%
TRICHOPTERA				
<u>Adults</u>				
Hydropsychidae	277	2.9	948	5.0
Psychomyiidae	0	--	3	--
Calamoceratidae	0	--	6	--
Hydroptilidae	0	--	12	--
Unidentified	1	--	44	0.2
<u>Larvae</u>				
Hydropsychidae	18	0.2	93	0.5
Psychomyiidae	13	0.1	5	--
Phryganeidae	1	--	0	--
Rhyacophilidae	0	--	2	--
Unidentified	13	0.1	27	0.1
TOTAL TRICHOPTERA	415	4.4	1,140	6.0
EPHEMEROPTERA				
<u>Adults</u>				
Subimagos	0	--	0	--
Unidentified	8	0.1	0	--
<u>Nymphs</u>				
Baetidae	1	--	24	0.1
Unidentified	0	--	4	--
TOTAL EPHEMEROPTERA	9	0.1	28	0.1
HYMENOPTERA				
<u>Adults</u>				
Unidentified	26	0.3	27	0.1

Table 2. (cont'd)

Food Organism	1968		1969	
	Number	%	Number	%
HOMOPTERA				
<u>Adults</u>				
Aphididae	49	0.5	245	1.3
Aleyrodidae	1	--	0	--
Unidentified	40	0.5	28	0.1
TOTAL HOMOPTERA	90	1.0	273	1.4
COLLEMBOLA				
Hypogastruridae	115	1.2	974	5.1
OTHER INSECTS				
Thysanoptera	35	0.3	11	0.1
Megaloptera	1	--	1	--
Unidentified Adults	0	--	98	0.5
Unidentified Larvae	0	--	11	0.1
Unidentified	165	1.8	51	0.3
TOTAL OTHER INSECTS	201	2.1	172	1.0
TOTAL INSECTS	8,997	95.6	18,704	98.4
OTHER FOOD ITEMS				
Fish Larvae	0	--	18	0.1
Acari	276	2.9	169	0.9
Zooplankton	30 ⁽³⁾	0.3	15 ⁽³⁾	0.1
Nematoda	7	--	11	--
Algae	1 ⁽⁴⁾	--	0	--
Arachnida	93	1.0	97	0.5
Plant Seeds	5	--	1	--
TOTAL OTHER FOOD ITEMS	412	4.4	311	1.6

1. Primarily emerging subadults.
2. Primarily Parargyractis sp. (Pyrallidae)
3. Number of fish containing small quantities of Cladocera, Ostracoda, Copepoda, or Amphipoda.
4. A quantity of Anacystis.

stages of aquatics, and winged adults of the terrestrials. The insects utilized were essentially similar in both years, and no major change in fish food habits or availability of food organisms was evident.

The Tendipedidae (midges) was the dominant insect group utilized by young chinook. Tendipedids are important in the diet of many species of salmonid fishes inhabiting both lentic and lotic environments; the central Columbia, a relatively large and cold water stream, proved to be no exception. When subadults emerged, rising to the surface of the river to take flight, they were captured in abundance by feeding chinook in the Hanford area (64% in 1968, 58% in 1969). Uncased midge larvae apparently adrift in the water were utilized less extensively (17% in 1968, 18% in 1969). Few of the normally attached midge pupae were taken.

The order Diptera, dominated by the Tendipedidae, provided 83 and 78% of all insects utilized in 1968 and 1969, respectively. The other insect orders were of much less importance in terms of numbers but not necessarily in volume or nutritional value since sizes of different species vary considerably. The relatively large Trichoptera or caddisflies, consisting primarily of Hydropsyche cockerelli (Hydropsychidae), was numerically the second most important order. Like the midges, most caddisflies eaten were recently emerged adults associated with the water-surface interface. (Larval caddisflies, though abundant in the river, were presumably protected from chinook

predation by their sheltered habitats below stones.) Other orders of importance were the Hemiptera, primarily small Notonecta nymphs (Notonectidae), and the Collembolla (Hypogastruridae).

Few Ephemeroptera, which are often important dietary items of salmonids in other streams, and no Plecoptera occurred in the stomach contents. Unpublished data from limited bottom samples, sporadic drift samples, inspection of stones, and trapping of adult insects by light attraction at night indicate that mayflies and stoneflies are proportionately low in abundance in the central Columbia.

Seasonal Changes in Diet

Slight seasonal variations in the diet of juvenile chinook, which showed a relationship to fish size but was not clearly defined, was noted in 1968 (Becker, 1970a). The proportion of major insect groups utilized each month in 1969 is listed in Table 3, and the sizes of all fish comprising the monthly collections are illustrated in Figure 3. The mean number of insects per feeding fish showed an increasing trend from March through July, in correlation with fish growth. The Tendipedidae were heavily utilized each month, but the greatest proportion of minute larval midges were taken in early spring when small fish predominated. Hemiptera (i.e. Notonecta nymphs) and Collembolla, both consisting of small forms, received maximum utilization during April, May and June when rising river volumes (Figures 1, 2) inundated shoreline areas. Large adult Trichoptera were taken primarily in June and July, in correlation

Table 3. Monthly Changes in Food of Juvenile Chinook at Hanford in 1969, all Sampling Stations Combined (in percent).

Food Organism	Consumption per Month (Percent)				
	March	April	May	June	July
<u>Insect Group</u>					
*Diptera	99.5	88.8	70.2	77.2	84.8
Tendipedidae, adults	67.1	62.4	50.4	52.4	77.2
Tendipedidae, larvae	31.8	24.6	17.4	22.8	6.3
*Hemiptera	--	3.2	13.2	2.6	T
Coleoptera	T	T	T	T	T
Lepidoptera	--	T	T	3.3	T
*Trichoptera	--	T	T	10.2	13.0
Ephemeroptera	--	T	--	T	T
Homoptera	--	T	T	3.4	T
Hymenoptera	--	T	T	T	T
*Collembola	T	5.6	13.8	1.4	--
Unknowns	--	--	T	T	--
All Other Insects	--	T	T	1.3	T
Total Insects (%)	99.5	97.6	97.2	99.4	97.8
<u>No. Fish Examined</u>	46	275	160	199	89
<u>Fish Size (mm)</u>					
Mean	39.4	39.9	44.1	49.4	58.7
Standard Deviation (+)	2.8	2.3	4.8	7.7	11.2
<u>$\bar{X}$ Insects/Feeding Fish</u>	15.9	13.2	32.7	28.9	43.9

Note: "T" = "Trace," or less than 1% by number in stomach contents.

* = Major insect groups utilized.

Figure 3. Length frequency distributions of juvenile chinook collected at Hanford, 1969.

with the summer emergence of the univoltine caddisfly populations. Adult Lepidoptera, consisting primarily of the semiaquatic Pyralidae, were taken most heavily when emerging in June.

Early Diet of Fry

The transitional period when young salmonids leave the gravel, commence active feeding, and develop swimming ability is a critical phase of their life. Chinook fry were relatively small (35-40 mm FL) when they emerged from the gravel of the riverbed. Apparently many of these fish were swept directly downriver, thereby giving rise to an early "migration" of fry similar to that noted by Mains and Smith (1964). The stomachs of 25 "migrating" fry captured by midriver traps in another study were found to be empty or nearly so.) Ten fry in 1968 and 39 in 1969, all collected in shoreline areas in April, had empty stomachs and also incompletely absorbed yolk sacs. The data reveal that feeding often started before the yolk was completely absorbed, when cold temperatures prevailed, and that food organisms selected in March and April were predominately small forms, primarily midges (Table 3).

Influence of Drift Organisms

Invertebrate drift in rivers and streams is an important phenomenon influencing the food and feeding activity of lotic freshwater fishes. Consideration of the developmental stages and biology of aquatic and semiaquatic insects ingested by young chinooks at Hanford indicates that most were floating, drifting or swimming in the water when captured. This was apparently the situation involving

selection of most Tendipedidae and Hydropsychidae, Notonecta nymphs and Hypogastruridae, the four main insect forms utilized. Few insect stages normally adhering to epibenthic substrates or living within gravel interstices were found.

Although endogenous insects predominated in the stomach contents, some exogenous terrestrial forms were ingested. The orders Homoptera, Hymenoptera and Thysanoptera are almost entirely of terrestrial origin, and other true terrestrials occur among the adult Diptera, Coleoptera and Lepidoptera, other than Pyralidae (Table 2). The terrestrials were probably seized while drifting, either submerged or on the surface film, and comprised less than 4% of the total food organisms by number. Thus the river drift of endogenous insects was important to the feeding of juvenile chinook at Hanford and the majority of the food organisms clearly originated within the river ecosystem.

ANALYSES FOR POTENTIAL THERMAL EFFECTS

Analyses to detect possible thermal effects on the food, feeding and growth of juvenile chinook in the Hanford environs were based on samples obtained at three stations above the discharge areas ("coldwater" stations) and three below ("warmwater" stations). Since the stations were located near the shore, the WWS were not directly exposed to thermal increments from primary mixing zones of the midriver discharge plumes. Consequently, temperatures at the WWS were, at the most, only a few degrees above those occurring in

the river above Hanford. An exception was Station D, which received heated effluent from intragravel seepage in early spring. All stations were partially warmed by solar radiation during sunny days in May, June and July, particularly the backwater and slough areas. Heat increments from both reactor and solar sources varied at each station in relation to ambient water levels, which affected current patterns and mixing with water in the main channel.

Analyses of data to detect any thermal effects, therefore, could be conducted only on the basis of general aspects. Two broad approaches were made. First, by comparing food and feeding parameters and, second, by comparing growth parameters.

Insects consumed by feeding chinook were produced either at or near each station, or from the river above (organisms conveyed in the drift), but the precise proportions could not be determined. Insects at the CWS, above the reactors, were assumed to have had no exposure to heated effluents whereas insects at the WWS, below the reactors, may have been influenced particularly if conveyed in the river drift.

Interstation groups of fish appeared to vary as a result of rapid turnover. Chinook at the CWS were assumed to have no previous exposure, directly or indirectly, to effluent discharges since the prevailing direction of fish movement in a large river like the Columbia is downstream. Although fish from the WWS may have been subject to heat increments from effluent discharges, there was no way to quantify the "exposure duration" of individuals in such

mobile and transient groups.

Food Organisms Utilized

The major food organisms utilized by juvenile chinook at each station throughout the season are summarized in Table 4. On a proportional basis, considerable variation occurred between stations and some intersite influences were evident. Adult midges were highly utilized at Station D (70.1%), a backwater area subject to intragravel seepage, but not larvae midges (6.1%). Notonecta nymphs were captured primarily at Stations A (7.3%) and E (7.4%), both with extensive areas of marginal vegetation. Hydropsyche adults were taken primarily at Stations B (9.2%) and C (7.2%), both with rubble bottoms and partially exposed to flow of the main channel, but larval caddisflies were captured primarily at Station C (9.0%). Collembola were utilized most heavily at Stations A (16.5%) and D (6.0%) where extensive mud-water interfaces existed.

Station D, subject to intragravel seepage over the preceding winter and during the spring, was the only station exposed directly to heated effluent. Larvae Tendipedidae, which normally live on benthic substrates in tubes of sediment molded by body secretions, apparently were numerically low at this site. However, adult Tendipedidae were abundant in the stomach contents of fish collected at Station D, indicating that flying adult midges were attracted to this warmed area in early spring when water (and air) temperatures remained fairly low.

Table 4. Proportions of Major Insect Groups Utilized by Juvenile Chinook at "Coldwater" and "Warmwater" Stations, all 1969 Data Combined (in Percent).

Food Organism	Coldwater Stations ⁽¹⁾				Warmwater Stations ⁽¹⁾			
	A	B	C	Total	D	E	F	Total
All Diptera:	67.4	78.2	75.7	71.6	79.5	77.5	84.9	80.4
Tendipedidae, adults	38.1	44.3	49.8	41.3	70.1	60.0	60.6	64.4
Tendipedidae, larvae	26.6	31.1	24.3	27.6	6.1	15.9	21.9	13.5
All Hemiptera:	7.9	4.9	2.6	6.4	4.3	7.4	1.2	4.4
Notonectidae	7.3	4.6	2.6	5.9	4.2	7.4	1.1	4.2
All Trichoptera:	6.3	9.6	16.6	8.5	6.6	6.0	3.3	5.5
Hydropsychidae, adults	5.9	9.2	7.2	7.0	6.1	4.8	2.5	4.7
Hydropsychidae, larvae	0.0	0.1	9.0	1.1	0.2	0.2	0.0	0.1
Collembola:	16.5	2.2	0.0	10.3	6.0	2.7	1.2	3.7
All "adults" ⁽²⁾	73.0	67.3	64.4	70.3	91.5	82.7	76.1	84.5
All "larvae" ⁽³⁾	27.0	32.7	35.6	29.7	8.5	17.3	23.9	15.5

1. Cold and warmwater stations were located above and below the reactor discharges, respectively.
2. Includes all winged forms, aquatic insects as well as terrestrials, plus the Hemiptera and Collembola.
3. Includes larvae, pupae, nymphs and other stages normally associated with benthic substrates.

On the basis of totals, more adult midges were taken at WWS (64.4%) than at CWS (41.5%) and more larval midges were captured at CWS (27.6%) than at WWS (13.5%). This suggests, superficially, that the rate of tendipedid development below the reactor discharges was increased by the relatively slight thermal additions, as will occur under laboratory conditions. I believe, however, that this was a spurious correlation under the field situation in this study. It is probable that proportional variations between stations (except for Station D) were more influenced by intersite features, including (but not restricted to) type of substrate, extent of exposure to current flow, changes in seasonal and regulated water levels, and possibly feeding preferences between individual fish.

Since intersite variations appeared to occur independently of thermal effects, statistical comparison of food organisms on a strictly numerical basis appeared to be largely irrelevant. In addition to variations between and within stations, the number and types of insects eaten deviated widely between individual fish comprising each collection.

Food and Feeding Activity (Rank Correlation Coefficient)

A desirable statistic to compare gross changes in feeding activity should be independent of normality, and be easy to compute and interpret. The nonparametric rank-correlation coefficient (r), as applied by Rodgers (1968), was deemed to be suitable. The formula is:

$$r = 1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

where 6 is a constant, d is the difference between two ranks, and n is the number of categories ranked.

The rank-correlation coefficient is applied here as an index of food similarity between the total of all comparable samples. It is largely independent of total numbers of individual organisms. A value of +1.0 indicates that the major food items were utilized in the same order of preference, and as r approaches -1.0, agreement in food utilization decreases. Therefore, r is a measure of similarity (or dissimilarity) in feeding activity of fish collected above and below the heated effluent discharges.

Comparisons of major food items by rank-correlation coefficients for the 1969 data are presented in Table 5. Since $r = +0.93$, there was a strongly positive relationship over the entire season. Monthly comparisons are illustrated in Figure 4. (March is omitted due to lack of samples from coldwater stations). Positive relationships are also shown for each month (April, $r = +0.88$; May, June, and July, $r = +0.95$), indicating that juvenile chinook above and below the heated discharges were utilizing the same kinds of foods. However, the relative proportion of these foods varied throughout the spring.

Food and Feeding Activity (Percent Similarities)

Although juvenile chinook at all stations utilized the same kinds of food according to rank, Table 4 and Figure 4 suggest that there were significant differences in feeding habits on the basis of relative proportions. To explore these differences more fully, the percentages of major food organisms in the stomach

Table 5. Comparison of Major Food Organisms Consumed by Juvenile Chinook at Cold and Warmwater Stations by Rank Correlation Coefficient (r'), all 1969 Data Combined⁽¹⁾.

Food Organism	Category	Coldwater Stations		Warmwater Stations		Difference	
		Percent	Rank	Percent	Rank	d	d ²
Adult Insects	A	70.3	1	84.5	1	0	0
Larvae Insects	B	29.7	3	15.5	3	0	0
Tendipedidae, adults	C	41.3	2	64.4	2	0	0
Tendipedidae, larvae	D	27.6	4	13.5	4	0	0
Hemiptera (Notonectidae)	E	6.4	7	4.4	6	-1	1
Hydropsychidae, adults	F	7.0	6	4.7	5	-1	1
Hydropsychidae, larvae	G	1.1	8	0.1	8	0	0
Collembola	H	10.3	5	3.7	7	+2	4

n = 8

$\Sigma d = 0$

$\Sigma d^2 = 6$

$r' = +0.93$

1. Monthly comparisons of r' are shown in Figure 4.

FIGURE 4. Rank correlation coefficients (r') for major food organisms ingested by juvenile chinook each month at cold and warm water stations.

contents within and between stations were tabulated on a monthly basis (Table 6). Since the category "Diptera" corresponded closely to total Tendipedidae, it was eliminated from Table 6 and the category "All Other Insects" was included to bring the column totals to unity.

According to Whittaker and Fairbanks (1959), the most widely used measurement for comparing animal communities compares them by numbers of individuals of species within the groups (stations) being studied by the formulae:

$$PS_c = 100 - .5 \sum [a-b] = \sum \min (a,b)$$

where a and b are, for a given species, the percentages of samples A and B which that species represents. The method is called "percentage similarity of community samples", and it quantitatively measures the relative similarity of numerical composition in terms species populations.

Direct computation of percentage similarities from Table 6 is possible through either of two procedures. To illustrate, the seven categories listed for April at Stations A and B are compared:

$$\begin{aligned} PS_c &= 100 - .5 \sum [a-b] = 100 - .5 [(70.5 - 24.2) + (61.0 - 21.8) + \\ &(11.1 - 5.1) + (0.0 - 0.0) + (0.0 - 0.0) + (0.0 - 1.3) + (3.6 - 1.3)] = \\ &100 - .5 \times 95.1 = 52.4. \text{ Or, more simply, the percentage values are} \\ &\text{summed for all species shared by the two samples: } PS_c = \sum \min (a,b) = \\ &24.2 + 21.8 + 5.1 + 0.0 + 0.0 + 0.0 + 1.3 = 52.4. \end{aligned}$$

Percentage similarities (PS_c) for all possible combinations of samples were compiled and entered in a diamond matrix (Figure 5).

Table 6. Monthly Variations in Proportions of Major Food Organisms Utilized by Juvenile Chinook at Cold and Warmwater Stations (in Percent)⁽¹⁾

Food Organism	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July
	<u>Station A</u>				<u>Station B</u>				<u>Station C</u>				<u>All Coldwater Stations</u>			
Tendipedidae																
Adults	24.2	78.7	52.1	73.7	70.5	81.7	27.3	--	48.8	--	27.9	46.3	37.7	37.6	34.0	62.6
Larvae	61.0	32.0	9.4	0.3	21.8	2.9	48.9	--	29.0	--	52.9	30.5	46.1	27.1	39.1	12.5
Hemiptera (Notonectidae)	11.1	8.9	7.2	0.3	5.1	8.6	1.7	--	3.4	--	0.3	0.2	7.9	8.7	2.9	0.3
Hydropsychidae																
Adults	0.0	0.0	16.4	23.4	0.0	0.0	12.9	--	0.0	--	10.4	5.3	0.0	0.0	13.5	16.1
Larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0	--	0.0	17.3	0.0	0.0	0.0	7.0
Collembola	0.0	25.9	5.3	0.0	1.3	3.4	0.0	--	0.0	--	0.0	0.0	0.1	22.1	1.4	0.0
All Other Insects	3.6	4.8	9.6	2.3	1.3	3.4	9.1	--	18.8	--	8.4	0.5	8.2	4.6	9.1	1.6
	<u>Station D</u>				<u>Station E</u>				<u>Station F</u>				<u>All Warmwater Stations</u>			
Tendipedidae																
Adults	49.8	83.6	67.9	60.3	83.8	70.3	46.8	50.7	44.8	62.5	59.0	92.8	57.9	73.4	57.8	85.0
Larvae	13.1	2.3	6.2	7.9	5.8	7.4	26.3	8.2	49.3	5.5	16.1	3.0	23.5	4.8	16.2	4.1
Hemiptera (Notonectidae)	5.3	8.7	1.7	0.4	2.2	14.8	3.3	3.7	0.6	22.0	2.4	0.1	2.8	14.4	2.5	0.3

Table 6. (cont'd)

Food Organism	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July
Hydropsychidae																
Adults	0.0	0.0	12.2	17.4	0.0	0.0	7.7	26.9	0.0	0.0	1.1	3.2	0.0	0.0	7.2	6.8
Larvae	0.0	0.0	0.0	0.0	0.7	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.2	0.1
Collembola	26.1	4.1	2.2	0.0	4.9	4.1	0.8	0.0	0.0	1.5	1.7	0.0	10.9	3.4	1.5	0.0
All Other Insects	5.7	1.3	9.5	14.0	2.7	3.4	14.9	10.4	5.4	8.5	19.7	0.9	4.7	4.0	14.6	3.7

1. Coldwater stations (A, B, C) and warmwater stations (D, E, F) were located above and below the heated reactor discharges, respectively.

Values of combined samples for all CWS and all WWS ranged from a low of 58.5 in May, 68.8 in April, 70.4 in June, to 75.5 in July (dark areas). Thus the lowest similarity occurred in May, the greatest in July. Monthly computed figures within either CWS or WWS, or between them, ranged above and below these values. No consistent pattern was evident. A WWS (E, F, or G) sometimes showed a high similarity value when compared with a CWS (A, B, or C) and sometimes a low value. For example, values for Station F versus A were high in April (77.7), June (74.8), and July (78.3) but low in May (49.2). These computations were concomittant with the conclusion that intersite feeding variations occurred largely independently of effluent discharges, in response to physical features of each station and feeding activity of individual fish.

Of particular interest are similarity values for Station D, a WWS subject to warm effluent via intragravel seepage in early spring. Compared with all CWS (averaged data), the values were lowest in April (61.9), May (54.0) and June (64.6) and highest in July (86.2). This may reflect gradual cessation of seepage after spring closure of the C reactor, accompanied by flushing of Station D during the annual spate.

Numbers of Insects Consumed

The mean numbers of insects per stomach of feeding fish are summarized in Table 7. Numbers at all stations revealed a general increase from March to July, in correlation with both increasing water temperatures and size of fish. During March and April, when

Table 7. Mean Numbers of Insects per Stomach of Feeding Chinook at Cold and Warmwater Stations. (Number of Fish Examined in Parentheses.)

Month	Coldwater Stations				Warmwater Stations				All Stations	Mean Size (mm)	Temp. Range (°C)
	A	B	C	Total	D	E	F	Total			
March	-- (0)	-- (0)	-- (0)	-- (0)	10.6 (30)	-- (0)	-- (0)	10.6 (30)	10.6 (30)	39.4	3-6
April	16.3 (22)	8.7 (9)	6.3 (33)	10.1 (64)	8.8 (66)	9.8 (46)	14.6 (37)	10.4 (149)	10.3 (213)	39.9	6-9
May	78.6 (30)	23.8 (20)	-- (0)	56.7 (50)	28.8 (40)	30.8 (30)	27.3 (30)	28.9 (100)	38.2 (150)	44.1	9-13
June	18.1 (27)	28.3 (40)	29.7 (10)	24.9 (77)	35.9 (32)	28.6 (40)	26.0 (40)	29.8 (112)	27.8 (189)	49.4	13-16
July	30.8 (20)	-- (0)	41.7 (10)	34.4 (30)	23.9 (20)	13.4 (10)	105.8 (20)	54.6 (50)	47.0 (80)	58.7	16-20
Total	38.6 (99)	24.4 (69)	17.4 (53)	29.1 (221)	19.5 (188)	21.0 (126)	35.6 (127)	24.6 (441)	26.1 (662)		

Note: (1) Cold and warmwater stations were located above and below the heated effluent discharges, respectively.

(2) Nonfeeding fish, all with remnants of yolk sac, were omitted.

river temperatures were low (3-9° C) and fry measured about 35-45 mm, mean numbers of insects per stomach were low (about 10/fish). Mean numbers increased to 38 in May, but were influenced by high consumption of Hypogastruridae at Station A (20 May sample). Mean numbers reached 47 in July, but were dominated by high consumption of adult midges at Station F (29 July sample), when river temperatures ranged from 16-20° C and the sampled fish were attaining maximum size.

High variations within and between samples precluded meaningful statistical comparison between cold and warmwater stations on the basis of mean numbers of insects per stomach. Although slightly higher means were recorded for the CWS (29/fish) than the WWS (25/fish), this had little practical significance. Feeding was most intense at one CWS (Station A) and one WWS (Station F), both slough-like areas.

Juvenile chinook were found in March only at Station D, subject to heated effluent via intragravel seepage. Presumably some of the first emerging fish were attracted to the site by the warmed water when river temperatures were near minimum (3-5° C). In 1968, numbers of insects per fish at Station D were low in early May in comparison with sites sampled. However, mean numbers in March, April, and May of 1969 (before closure of the C Reactor) did not appear to differ greatly from the other stations (Table 7). The length frequency distribution of fish collected in March (Figure 3) was based entirely on individuals collected at Station D; growth of this early group appeared to be rapid because fish lengths in April

greatly exceeded those of fish collected at other stations.

On the basis of Table 7, the numbers of insects per stomach may increase with the size of the fish and this relationship may be linear. The mean number of insects per stomach in relation to mean size of fish collected at all the CWS and all the WWS on each sampling date is illustrated in Figure 6. No linear relationship was apparent. Except for some fry that carried remnants of the yolk sac, all fish contained food but the numbers of organisms varied widely (even between sample means). Letter (a) on Figure 6 reflects high consumption of Hypogastruridae on 20 May (Station A), while letter (b) reflects intensive feeding of large fish in the final collection of 29 July (Station F).

Number of insects per stomach under field situations is, at best, a rough index to the adequacy of feeding and subsequent growth. There are several reasons. First, insects vary widely in size from minute midges to large caddisflies; a fish might contain large numbers of small insects that would still not equal a few large insects in terms of energy supplied. Second, the relative nutritional value may vary between like amounts of different kinds of food organisms. Third, stomach contents reveal only feeding at the approximate time a sample was taken and not the preceding meals responsible for growth. Fourth, digestion rates, metabolism and energy consumption that result in growth are highly temperature dependent, particularly over the March to July range of 3 to 20° C that occurs in the central Columbia. Fifth, changes in water levels

FIGURE 6. Numbers of Insects Per Stomach Content in Juvenile Chinook from Cold and Warm-water Stations, March-July 1969

influence current patterns, availability of the food supply and, more or less, expenditures of energy required for a fish to obtain a "full meal".

Seasonal Increases in Fish Length

Growth in length of juvenile chinook, as revealed by consecutive interstation samples from March to July, is illustrated in Figure 7. Growth (sample means) was relatively slow and uniform at each station during April and early May when recruitment to shoreline zones was initiated and temperatures were low. Variations in mean sample lengths appeared with further growth in late May, as temperatures increased, and became extreme within and between stations in June and July. These variations suggest considerable turnover of fish at each station, as might be expected in a population composed of transitory groups. Interstation turnover probably resulted from irregular movements along the shoreline and migration in response to physiological stimuli, fluctuating water levels and rising water temperatures.

For the above reasons, statistical comparison of mean fish lengths between samples in relation to station and time was deemed inappropriate for evaluation of possible thermal effects. Nevertheless, comparisons of group means were made by Duncan's Multiple Range Test and the results are given in Table 8. The test supports deductions based on Figure 7 by demonstrating significant differences between sample means, particularly in late May, June, and July.

FIGURE 7. Growth of juvenile chinook collected from stations above (coldwater) and below (warmwater) the Hanford effluent discharges, March-July 1969.

Table 8. Summary, Statistical Comparison of Sample Mean Lengths (mm) by Duncan's Multiple Range Test (Within Cold and Warmwater Stations).

Date	Warmwater Stations ⁽¹⁾⁽²⁾			Group Mean	Number Fish	Standard Deviation
	D	E	F			
3/4	38.69	-----	-----	38.68	19	2.19
3/11	38.90	-----	-----	39.90	10	1.66
4/8	40.50 <u>A</u>	39.35 <u>B</u>	39.33 <u>B</u>	39.76	55	1.53
4/15	40.26	39.70	39.80	39.71	38	2.46
4/24	39.55	39.50	40.43	39.70	37	1.85
4/29	39.94	40.50	41.50	40.50	38	3.62
5/13	40.35	42.20	41.20	41.03	40	3.05
5/20	41.90 <u>A</u>	45.60 <u>B</u>	48.80 <u>C</u>	43.43	30	4.35
5/27	45.10	49.10	46.50	46.90	30	4.46
6/3	43.80 <u>A</u>	43.10 <u>A</u>	49.10 <u>B</u>	45.33	30	4.34
6/10	37.75 <u>A</u>	50.20 <u>B</u>	49.70 <u>B</u>	46.46	28	7.05
6/16	65.00 <u>A</u>	50.30 <u>B</u>	55.40 <u>B</u>	56.90	30	9.03
6/24	-----	48.60 <u>A</u>	58.00 <u>B</u>	53.30	20	8.05
7/2	53.60 <u>A</u>	49.70	60.60 <u>B</u>	54.63	30	8.30
7/7	49.80	-----	-----	49.80	10	4.05
7/29	-----	-----	78.10	78.10	10	5.20

Date	Coldwater Stations ⁽¹⁾⁽²⁾			Group Mean	Number Fish	Standard Deviation
	A	B	C			
4/8	-----	-----	39.65	39.65	20	1.90
4/15	38.40 <u>A</u>	-----	40.40 <u>B</u>	39.40	20	1.70
4/24	40.40	-----	40.80	40.60	20	2.23
4/29	40.50	41.70	-----	41.10	20	1.92
5/13	38.90	-----	-----	44.60	10	4.18
5/20	45.20	44.00	-----	44.60	20	5.05
5/27	43.70	47.50	-----	45.60	20	4.78
6/3	50.70	49.40	-----	50.05	20	3.65
6/10	-----	54.90	-----	54.90	10	3.60
6/16	51.86	46.30	52.40	50.00	27	6.20
6/24	59.20 <u>A</u>	50.70 <u>B</u>	-----	54.95	20	9.54
7/15	63.40 <u>A</u>	-----	55.90 <u>B</u>	59.65	20	8.01
7/21	68.10	-----	-----	68.10	10	5.80

(1) Means in a horizontal line with a different common letter are significantly ($P < 0.05$) deviated from overall mean.

(2) Corresponding data are illustrated in Figure 5.

Since sample means within and between stations differed widely, statistical comparison of grouped means from the CWS and the WWS would probably be meaningless. Instead, comparison was made on the basis of length-weight relationships in the following subsection.

A clearer picture of growth in relation to the seasonal increase in river temperatures, however, is shown in Figure 8 where the mean lengths of all juvenile chinook collected at the CWS and the WWS are compared. The slight curvilinear relationship indicates, as expected, that growth rates increased under warming temperature regimes in June and July.

Fish Length-Weight Relationships

Length is but one parameter of growth. Another approach is to explore length-weight relationship of juvenile chinook collected at all CWS and all WWS (irrespective of time), as illustrated in Figure 9. The relationship was essentially linear for young chinook of the 35-80 mm size range.

For statistical analysis, several models were first fitted to the pooled length-weight data from the two station categories. Both biological and statistical considerations indicated the use of a nonlinear least squared fitted power function to model the data. Some nonrandom deviations of points from the fitted line were evident (as in all models tried), but "eyeball fit" was excellent for practical purposes. No significant statistical difference was found for the fitted lines, and therefore proportionate allometric development was a conclusion consistent with all data. Length-weight relationships

FIGURE 8. Growth of juvenile chinook collected at cold and warmwater stations, March-July 1969, in relation to Columbia River temperatures.

FIGURE 9. Length-weight relationships of juvenile chinook from cold and warmwater stations, March-July 1969.

of juvenile chinook collected at all CWS and all WWS were approximately equal.

Fish Coefficients of Condition

Since no significant differences appeared in statistical comparison of fish length-weight relationships, it might be expected that the coefficients of condition would also be nearly equal. In this situation, it is desirable to compare the condition of fish in 10 mm size groups in combined samples from all CWS and all WWS. In fisheries biology, the coefficient of condition (Q) is used primarily as an aid in determining the general physical status of fish stocks in different environments. The equation, as applied by Fraser (1969), is:

$$Q = \frac{W(10^5)}{L^3}$$

where W is the weight (gms) of the fish, L is the length (mm) of the fish, and the factor 10^5 brings the value of Q near unity.

Results of the calculations are given in Table 9. Q was low and equal (1.08) for both 36-45 mm size groups. Fish at this size were emerging from the gravel in early spring and beginning to feed at low temperatures. Q was nearly similar for the larger size groups at both CWS and WWS, ranging from 1.29 to 1.39. No major difference was evident, even for the larger fish that presumably dwelled and fed for the longest period of time under somewhat dissimilar thermal conditions above and below the effluent discharges.

Table 9. Mean Lengths, Mean Weights and the Coefficient of Condition (Q) for Different 10 mm Size Groups of Juvenile Chinook at Cold and Warmwater Stations, March-June 1969.

Size Group ⁽¹⁾	Coldwater Stations				Warmwater Stations			
	Number Fish	Length (mm)	Weight (gms)	Q	Number Fish	Length (mm)	Weight (gms)	Q
36-45 mm	120	40.84	0.74	1.08	291	40.33	0.71	1.08
46-55 mm	74	50.49	1.71	1.33	103	49.86	1.57	1.29
56-65 mm	27	59.44	2.83	1.35	30	58.77	2.70	1.33
66-75 mm	13	69.08	4.43	1.34	14	71.00	4.92	1.37
76-85 mm	2	77.50	6.32	1.39	6	79.50	6.60	1.31

(1) Fish less than 36 mm and over 85 mm in fork length were omitted due to scarcity.

Stomach Biomass

The stomach biomass reflects feeding intensity only within a short time preceding collection. Digestion, metabolic rates, and energy expenditures increase with a rise in river temperature. All samples in this study were collected during the day and, except for some fry retaining remnants of yolk sac, all fish contained some food organisms. Extreme variations between and within samples, however, precluded meaningful statistical comparison between the CWS and the WWS on the basis of stomach biomass of the fish. (Similar variations were evident in mean number of insects per feeding fish.)

Nevertheless, stomach biomass provides an indication of feeding activity that intensifies with fish size as temperatures rise and the season advances. This parameter is independent of number of insects, because sizes of different insects vary (i.e. minute midges versus large adult caddisflies). A comparison of dry weight of the stomach contents by combining means at all CWS and all WWS on successive sampling dates is given in Figure 10. Juvenile chinook in March were found only at Station D, subject to warm effluent via intragravel seepage, and feeding at this station was apparently satisfactory. Dry weights of stomach biomass were minimum in April, when movement of fry into shoreline feeding areas was initiated, but increased during the following months as the fish attained greater sizes and temperatures warmed. Considerable variation between consecutive samples was evident in June and July.

FIGURE 10. Seasonal changes in dry weight of stomach contents of juvenile chinook from cold and warmwater stations, March-July 1969.

The mean stomach biomass in relation to mean size of fish collected at all CWS and all WWS is illustrated in Figure 11. Biomass increased with size, but the relationship was not strictly linear because of variations even between the grouped samples. Statistical comparison between samples collected at all CWS and all WWS was made by calculating regression lines with the standard equation:

$$E(Y/\bar{X}) = \alpha + B(X_i - \bar{X})$$

where E is the estimate, Y is the dry weight of stomach contents, X is the length of the fish, α is the combined mean dry weight and B is the slope.

The regression lines differed significantly (Figure 11). Weight of the stomach contents apparently increased more rapidly with fish size at the CWS than at the WWS. However, the slope for the WWS was lowered by the final sample of largest fish ($\bar{X}$ 78.1 mm) in late July at Station F (Table 1). These fish may have moved downriver from areas above the effluent discharges. For this reason, and because of variations between and within samples, the difference was not considered to be ecologically significant.

DISCUSSION

Food of Young Chinook Salmon

Published data on food and feeding of young chinook are fragmentary. In an early study, Rutter (1904) reported that young chinook in the Sacramento River system, California fed primarily upon floating or drifting insects and that immature stages formed the

FIGURE 11. Dry weight of stomach contents in relation to size of juvenile chinook from cold and warmwater stations, March-July 1969.

greatest portion of their food. Chapman and Quistorff (1938), who examined juvenile chinook from tributaries of the Columbia River above Hanford, also found that the fish fed almost exclusively on insects, although collections were made during the summer and fall and the fish were large, up to 152 mm (possibly yearling spring chinook); the order Diptera was of greatest numerical importance but relatively few if any midges (Tendipedidae), a group of major importance at Hanford, were included. Breuser (1954), in an unpublished thesis, found that young chinook in the middle Willamette River, Oregon utilized mostly Diptera (39%), primarily midge larvae, and Ephemeroptera (40%).

Perusal of other published records (unlisted here for brevity) dealing with food habits of young salmonids other than chinook (i.e. salmon, trout and charr) reveal that insects, primarily aquatic but also some terrestrial forms, are the predominant food organisms utilized in lotic habitats. Clemens (1934) found that young chinook residing in a lentic environment (Suswap Lake, British Columbia) fed primarily on terrestrial insects, small crustacea and various stages of aquatic Tendipedidae. The literature indicates that food habits of young chinook are essentially similar to those of young coho salmon (O. kisutch), a closely related species.

The distinctive features of chinook feeding in the central Columbia appear to be fourfold: first, relatively few insect groups were utilized; second, the fish depended on drifting, floating, or swimming organisms; third, they visually selected living prey

moving in or on the water; and fourth, they were habitat opportunists to a large degree. These features are not necessarily unique among young salmonids, but here they demonstrate a close relationship with conditions in the Columbia River ecosystem.

Within aquatic habitats, the production of insect groups may be influenced by numerous environmental variables including water temperature, water quality, current velocity and discharge, type of substrate, water depth, and predation rate. Insects are but one link of the aquatic food chain and they, in turn, feed upon other insects, algae, or detritus (Chapman and Demory, 1963). The production of these smaller food organisms, at a lower trophic level, are in turn influenced by a complex of environmental factors including temperature regimes.

Ecological Aspects of Food and Feeding

The central Columbia is a large river with a relatively vast water mass, rapid current flow, and minimum shoreline habitat in relation to discharge volume. Living in stream environments requires considerable expenditure of energy that must be at least balanced by food consumption. Growth occurs only when energy provided by food exceeds energy expended in feeding and other activities. Mundie (1969) postulated that energy can be conserved in three ways: by leaving stream conditions to enter a lake or sea, by living in the stream below the main impact of the current, or by living predominantly in slack water, in pools and in marginal back eddies. He believed that young coho salmon in a British Columbia stream saved

energy primarily by living near the stream margins. Chapman and Bjornn (1969) found that young chinook and steelhead in Idaho streams were associated with velocities and depths in relation to body size, shifting to faster and deeper water as body growth occurred. My observations indicate that juvenile chinook in the central Columbia also live primarily near the stream margins or wherever currents are reduced. At any rate, all samples were obtained entirely from marginal areas that could be effectively seined, thus reflecting feeding in these habitats, and a possible shift of large fish to deep water would not be detected.

Production of aquatic insects is known to vary widely among different types of substrate and even within a given type of substrate. However, reliance of juvenile chinook on swimming or drift organisms in the central Columbia tends to reduce the influence of substrate type on foods available at each station sampled. Since insects entering the drift are produced in upriver areas as well as at each station, the food organisms presumably originate from a complex of substrate types. Waters (1969) noted that the significance of invertebrate drift to stream fish is that of increasing the availability of food, and interstation limitations on insect production are supplemented by drift organisms; moreover, under conditions of high discharge (as occurs each spring in the central Columbia) the quantity of drift passing downriver per unit of time is higher than under low flow conditions.

Drift organisms often exhibit diel periodicities because many taxa are night active, and this phenomena may have influenced the food and feeding of young chinook at Hanford. Since my samples were collected during daylight hours, the data reflect diurnal feeding activity. However, feeding is presumably more intense during the day because visual stimulation is an important factor in the feeding of salmonids (Chapman, 1966). According to Waters (1969), five major aquatic taxa are prominent in exhibiting diel periodicities: amphipods; the insect orders Ephemeroptera, Plecoptera, and Trichoptera; and the family Simuliidae (Diptera). Noticeably absent in drift periodicities are most burrowing forms, large strong-swimming predators, molluscs, stone-cased Trichoptera, and dipterans other than Simuliidae, particularly the chironomidae (Tendipedidae) even though sometimes abundant. Thus midges, of major importance to Hanford chinook, were presumably equally available during the day and night.

A major factor influencing the magnitude of diel periodicities is the current velocity (Waters, 1969). Thus an increase in drift organisms that presumably occurs during the Columbia's spring spate would increase the quantity of food available to young chinook during their period of maximum abundance. The entraining factor for night-active drift appears to be decreasing light intensity, whereas day-active drift may respond primarily to temperature (Waters, 1969). Temperatures in a large river like the central Columbia, however, show little if any consistent fluctuation within 24 hr periods.

No data on preference for a particular food organism by juvenile chinook was obtained in this study. Determination of preference depends primarily on the concentration ratios of ingredients making up the food complex and their occurrence in the stomach of fish (Allen, 1942; Ivlev, 1961). Although some invertebrate drift samples were taken, which demonstrated an abundance of tendipedid larvae, they were inadequate for accurate determination of ratios over the entire season. It is assumed that feeding corresponded roughly to food organisms occurring free in the water, since benthic stages were not highly utilized, but not necessarily in proportion to what was available. Some selectivity was evident in that small fry utilized small midges, both adults and larvae, most extensively whereas fingerlings tended to prey on large food organisms such as adult Trichoptera (Table 3). The relationship of increasing fish size to increasing food size in young salmonids has been noted by others (Lindström, 1955; Hartman, 1958). Foods utilized by young salmonids are subject to limitations imposed by the size of the fish whereas food utilized by larger fish can be very diverse (Mundie, 1969). However, diversity is clearly limited to what is available in the ecosystem.

Since warmer temperatures increase metabolism, a greater number of insects must be consumed in order to maintain growth of fish as the season advances. The increase in number of insects with fish size (Table 3) thus correlates not only with growth but also with rising river temperatures (Figure 1). Midge larvae and adults are

individually low in nutritional value because of their minute size. Yet midges are utilized throughout the season by juvenile chinook at Hanford, and their abundance compensates for their small size. The large adult caddisflies ingested in June and July provide greater nutritional value when temperatures are high and more energy is required to maintain growth. (By dry weight, one adult Hydropsyche cockerelli is equal to 35 adult midges).

At Hanford, utilization of suspended organisms may well reflect variations in river flow. The annual increase in discharge in April and May (Figure 1) inundates shoreline areas that are exposed to air the entire preceding winter. Recolonization of flooded inshore areas depends primarily upon insect larvae in the drift, which may occur rapidly, and upon the deposition of eggs by adult aquatic insects. There are no available data on recolonization rates of inundated areas at Hanford. But Elliott (1967) states that detached animals spend only a short time in the drift and re-attach as soon as possible. The problem in the central Columbia is complicated by weekly and daily flow variations resulting from regulation of discharges at Priest Rapids Dam, which periodically floods and exposes shoreline areas (Figure 2). On this basis, it is not surprising to find food organisms in chinook stomachs that normally live near or along the shoreline, such as Notonecta nymphs, adult Hypogastruridae, and the terrestrial Arachnida (spiders).

Juvenile chinook commonly reside in relatively small home areas (ecological niches) for a period of feeding and growth prior

to seaward migration (Chapman and Bjornn, 1969; Edmondson, Everest and Chapman, 1968). Permanence of station in shoreline areas of the central Columbia, however, is likely curtailed by weekly and daily fluctuations in regulated water levels (Figure 2). The great difference in discharge volume between the peak spring spate (up to 280,000 cf/sec) and the summer period of low flow (down to 40,000 cf/sec) suggests that most lingering chinook are impelled from the Hanford area by falling water levels (Figure 1). The combination of rising then decreasing river flow accompanied by rising temperatures are the main environmental factors correlated with normal seaward migration. These factors, occurring annually since recorded history, may well have played an evolutionary role in the development of the spring migration characteristic for young fall chinook (Becker, 1970b).

Effects of Thermal Discharge

The ecological aspects reviewed above, particularly river flows regulated by hydroelectric power demand, extend to analyses of the effects of heated effluents on the food, feeding, and growth of juvenile chinook in the central Columbia. Realistic evaluation, however, recognizes that temperature increments shown in Figure 1 are valid only for 1969. The history of Hanford operations shows that six reactors were operating from 1944 to 1955, eight from 1955 to 1963, a maximum of nine in 1964, and six from 1965 to 1968 (Nakatani, 1969). Due to curtailment of plutonium production, only four reactors were operating in 1968 and early 1969.

The main effluent discharges at Hanford occur at fixed subsurface locations in midriver, and the mixing zones extend downstream in

relatively narrow bands. The horizontal distribution of the mixing zones widens at lower river flows, but the effluent plumes remain well away from the banks even at minimum flows of 40,000 ft³/sec (Templeton and Coutant, 1971). Consequently, juvenile chinook feeding in inshore areas are not directly exposed to thermal increments. In addition to the midriver discharges, a few locations along the south shore receive limited amounts of heated water via intragravel seepage from shoreline retention basins. Only one station (Station D) was subject to warming by seepage, and this was eliminated with the closure of the C Reactor during the spring of 1969. Regardless of location, water at all inshore stations during June and July was heated somewhat above temperatures of midriver by solar radiation. Proportional allotment of heat from reactor and solar sources at the WWS was not possible. It is ecologically significant that differences in river temperatures between Priest Rapids and Richland are relatively low (Figure 1). At least part of the summer heat increment in the free-flowing river above Richland (1-2° C) is due to solar radiation that occurs independently of reactor operations (Moore, 1969).

Analysis of length frequency distributions of fish collected at each sampling station reveals considerable variation from week to week. Seaward migration apparently occurs intermittently over the entire sampling period. For this reason, groups of fish available at each station are interpreted as being unstable and existing in dynamic equilibrium with recruitment from the gravel, direct seaward migration, and irregular movements along the shore.

Weekly and daily variations in river discharge induced at Priest Rapids Dam may implement population turnover by alternately flooding and exposing shoreline habitats. On this basis, "exposure" of fish to any effect of heated effluent discharges is largely temporary and is not necessarily reflected by gross changes in food, feeding activity, or growth.

Measureable thermal increments occurred at Station D from intragravel seepage in the spring of 1969 before closure of the C Reactor. An early group of chinook fry appeared at this station in March. Feeding was apparently satisfactory since the fish revealed rapid initial growth. But this small group disappeared and representatives were not collected after mid-April. In 1968, mean numbers of insects per stomach were lower in early May at Station D than at two other stations (Becker, 1969) but this effect was not apparent in 1969.

A number of reports in the literature show that fish acclimated to low temperatures often invade warm water in large numbers. Ferguson (1958) noted that generally the preferred temperature of fish living at low thermal levels is considerably higher than ambient, but that this difference decreases up to the final preferendum where both coincide. Presumably the warmer water attracted some chinook fry into Station D during March when river temperatures were cold ($3-5^{\circ}\text{C}$), well below a preferred level of $12-14^{\circ}\text{C}$ (Brett, 1952) for young salmonids.

Evaluation for possible thermal effects was made by analyses of both food and growth parameters. In general, food parameters varied

widely between and within stations, primarily because of interstation features and changing water levels, and growth parameters varied similarly because of interstation population turnover.

Numerical variations of insects consumed within and between stations were extreme. Comparisons by nonparametric rank correlation coefficient (r_s) indicated that juvenile chinook above and below the heated discharges were utilizing the same kinds of food each month (Table 5, Figure 4). Comparison of food organisms by quantitative percent similarities (PS_c) emphasized variations concomittant with intersite features, which apparently occurred independently of possible thermal effects (Table 6, Figure 5). Variations between and within samples precluded meaningful statistical comparison of mean numbers of insects per feeding fish at the different stations, although there was a general increase from March to April (Table 7) as the fish metabolism responded to warming temperatures and they increased in size. Sizes of juvenile chinook were variable within and between stations on successive sampling dates, particularly in late May, June, and July (Figure 7), and were indicative of population turnover. Growth tended to increase throughout the season as the river warmed (Figure 8).

Ivlev (1961) noted that an insufficiency of food within broad limits does not affect the fish population by decreasing their numbers, but rather by decreasing their rate of growth and a general decimation of starving individuals. Obviously organisms encountered in the stomach of a fish reveal only food components at the time a

sample was taken, and not continuity or adequacy of feeding. For these reasons, growth parameters are probably more valid than food parameters as indicators of any effects of heated effluent on juvenile chinook.

Statistical comparison of mean fish lengths between all samples revealed some small but significant differences (Table 8). But these differences were assumed to be meaningless because of the wide variability between samples on successive dates and an increase in standard deviation with growth (Figure 7). The length-weight relationships between chinook sampled at all CWS and all WWS, when combined and tested by nonlinear least squares power function, revealed no significant differences (Figure 9) and supported a conclusion of proportional allometric growth.

Coefficients of condition (Q) for fish collected at cold and warm water stations, grouped in 10 mm size groups, were essentially similar (Table 9). Final Q values for groups of coho and steelhead fry reared at different population densities in experimental channels in British Columbia (Frazer, 1969) were lower (1.13 - 1.21) than calculated here for juvenile chinook (1.31 - 1.39). Although the three species are not strictly comparable, the relative Q values suggest that food and feeding conditions in the central Columbia were favorable for growth of young chinook. Data obtained by Benson (1953) indicate a close relationship between coefficient of condition, periodicity of growth and stomach content volume for brook trout at optimum temperatures; Q values for this salmonid dropped rapidly under maximum

temperatures of the summer and fall.

Comparison of stomach biomass of chinook from CWS and WWS, on the basis of fish length, differed slightly but significantly when compared by regression analysis (Figure 11). This difference was considered to be of little practical importance.

Consideration of all data obtained in this study reveal no gross effects from existing effluent discharges on food, feeding and growth of juvenile chinook salmon in the Hanford environs. The principal reason for lack of detectable thermal effects apparently issues from the fact that the main effluent plumes discharge in midstream and the effluents are well mixed with the receiving river water before reaching inshore feeding areas. Inherent difficulties exist in evaluation of thermal effects on food and feeding in a river with the volume and physical features of the central Columbia. Moreover, the field situation, in contrast to the laboratory, is subject to numerous uncontrolled natural variables. The transient nature of the fish groups at each station, influenced by weekly and daily fluctuations in regulated river discharge volumes, and the availability of food organisms in the river drift are important ecological features affecting critical thermal evaluation in situ.

In retrospect, precise evaluation of possible thermal effects on food, feeding and growth of young salmon would be most feasible under semicontrolled conditions. Such studies would require artificial channels that simulate the river ecosystem, receive controlled thermal increments, are naturally seeded by populations

of aquatic insects and are stocked with known numbers of fry. However, would data thus obtained accurately reflect effects imposed on transitory groups of fish in the field?

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