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FOOD AND FEEDING OF JUVENILE CHINOOK SALMON
IN THE CENTRAL COLUMBIA RIVER IN RELATION TO THERMAL
DISCHARGES AND OTHER ENVIRONMENTAL FEATURES

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ABSTRACT

The relationship of thermal discharges from operating Hanford reactors to food and feeding of juvenile chinook salmon (Oncorhynchus tshawytscha) in the central Columbia River, Washington was studied in 1968 and 1969. The primary objectives were to (1) evaluate the food composition and feeding activities of the fish and (2) determine if heated effluents influenced their welfare. Environmental conditions (seasonal changes in river temperatures and flow volumes) in relation to thermal requirements of young chinook are detailed. Data on food organisms utilized by the fish in 1968 and 1969 are presented, whereas analyses for possible thermal effects are based on the more extensive 1969 data.

Young chinook at Hanford consumed primarily various stages of aquatic insects, of which adult and larvae Tendipedidae (Diptera) were of dominant importance. Other major food organisms were the order Collembola and the families Notonectidae (Hemiptera) and Hydropsychidae (Trichoptera). Small fry fed almost exclusively on tendipedids. The food composition was essentially similar in 1968 and 1969. Over 95 percent of food organisms utilized over the season originated in the river ecosystem.

Analyses to detect thermal effects were made on food and feeding parameters and on growth parameters compiled from fish collected at three sites above ("cold water stations") and three sites below ("warm water stations") the effluent discharges. The following comparisons were made:

(1) food organisms utilized, (2) feeding activity, (3) mean insects per feeding fish, (4) seasonal increases in fish length, (5) fish length-weight relationships, (6) coefficients of condition, and (7) dry weight of stomach contents.

All data were characterized by considerable variations between and within individual stations. No consistent differences attributable to thermal increments were evident.

The lack of detectable effects apparently results from the fact that the main discharge plumes occur in midriver and the effluents are well mixed before reaching inshore feeding areas. The transient nature of fish at each sampling site and the availability of food organisms in the river drift are ecological factors affecting critical thermal evaluation.

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INTRODUCTION

Studies on the relationship of thermal discharge to the food and feeding of juvenile chinook salmon (Oncorhynchus tshawytscha) in the Hanford environs of the central Columbia River, Washington were initiated in 1968 and expanded in 1969. The primary objectives of the field studies 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 influenced their welfare. The investigation was prompted by the possibility that disposal of effluents from operating plutonium production reactors and the resulting thermal increments might either be detrimental to the food organisms upon which juvenile salmon depended or effect their feeding activity and 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 in order to provide a firmer basis for evaluation of thermal effects. The results of this investigation are combined with previous work and detailed herein.

This report is separated into six sections: (1) a brief review of background literature dealing with, first, the food

of juvenile chinook and, second, various thermal effects on feeding and growth of fish; (2) methods used in this study for collection and analyses of samples; (3) environmental conditions in the central Columbia in 1969, primarily temperatures and discharge volumes; (4) presentation of data on food organisms and feeding activity; (5) analyses of data for potential thermal effects; and (6) discussion of, first, ecological aspects of food and feeding and, second, results of evaluation for effects of thermal discharges.

BACKGROUND LITERATURE

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 greatest portion of their food. Chapman and Quistorff (1938) examined juvenile chinook taken in tributaries of the north central Columbia River above Hanford. These fish also fed almost exclusively on insects, although collections were made during the summer and fall and the fish were relatively large, up to 152 mm (possibly yearling spring chinook). The order Diptera was of greatest numerical importance but relatively few midges (Tendipedidae), a species 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. other species of salmon, trout and charr)

reveal that insects, primarily aquatic but also terrestrial forms, are the predominant food organisms utilized in lotic habitats. Clemens (1934) found that young chinook residing in Suswap Lake, British Columbia fed primarily on terrestrial insects, small crustacea and various stages of the aquatic Tendipedidae. The literature also indicates that the food habits of young chinook are very similar to those of young coho salmon (O. kisutch), a closely related species.

Within aquatic habitats, the production of insect groups is influenced by numerous environmental variables including water temperature, water quality, current velocity and discharge, type of substrate, water depth, and predation. Insects are but one link in 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 particularly temperature regimes.

Thermal Effects Relating to Hanford Studies

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. For the majority of species, the precise interactions and ecological limits of multifacet thermal effects remain unknown.

Preferred temperatures for juvenile salmonids, where conditions are presumably 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°C (50-60°F) by Burrows (1963). Brett (1952)

also gave 25.1°C as the upper incipient lethal level for juvenile chinooks, where 50% of the fish die after one week of exposure. However, it is now known that the lethal limit of fish in nature may be somewhat less than determined under controlled laboratory conditions (Ferguson, 1958). Fish are sensitive to small temperature changes (in the order of 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), Mihursky and Kennedy (1967) and others. As noted by Allen (1941) in studies of young Atlantic salmon (Salmo salar), 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 tolerance but below the lethal level where feeding is restricted. Fingerling sockeye salmon (O. nerka) cease eating under experimental conditions when temperatures increase from 17.2 to 25.6°C (Donaldson and Foster, 1941), and the ability of brook trout (Salvelinus fontinalis) to capture prey 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).

(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. Although acceleration varies considerably, generally speaking, the metabolic rate doubles with each increase of 10°C .

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). Food consumption of brown trout (Salmo trutta) is greatest at 10-19°C, but the fish are so active at the high temperature that a large proportion of its food 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, indicates that there is undoubtedly an optimum temperature for metabolism, as revealed by feeding activity and growth rates, for each species of fish. (This temperature may roughly correspond to "preferred" temperature of individual species.)

Metabolism is reduced at temperatures below this optimum point and increased at temperatures above, both slowing the maximum growth rate. Sockeye fingerlings with optimum growth and food utilization at 10°C, produce poor growth at 4-7°C (Donaldson and Foster, 1941). Rainbow trout feed readily at low temperatures, but digestion takes 2-3 times longer at 1.6°C than at 10°C (Reimers, 1957). Young centrarchids consume about three times as much food per day at 20° as at 10°C (Hathaway, 1927). Survival time rates 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 high 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 food intake.

METHODS

Young chinooks of the 0-age group were collected by hand or 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 these 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 spans each year corresponded to the annual period of abundance and migration of juvenile chinooks in the central Columbia (Mains and Smith, 1964; Becker, 1970b). All samples were collected during daylight 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 some 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 contents of each fish was placed in a miniature watch glass, air dried at least 24 hours, 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,

Table 1. Summary of Stations Sampled and Number of Juvenile Chinook Per Sample in 1969 Food Analyses

Date	Number of Chinook Examined											Fish Per Date
	"Cold Water" Stations ⁽¹⁾					"Warm Water" Stations ⁽¹⁾						
	A	B	C	W	D	E	F	X	Y	Z		
March 4				14	19							19
11					10							24
25					2			3				3
April 1												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 warm water stations were located above and below the reactor discharges, respectively. Cold water stations A, B and C and warm water stations D, E, and F were used for analysis and comparison of food habits and growth.

three above the Hanford effluent discharges (A,B,C) and three below (D,E,F), and these were sampled more or less consistently (Table 1). Supplemental samples were scattered between four secondary stations (W,X,Y,Z). All samples were utilized in identification of food organisms, but only samples 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 levels, which ranged from about 40,000 to 280,000 ft³/sec over the season, handicapped consistent interstation sampling. Field records were kept on ambient surface water temperatures and substrate characteristics at each station. Interstation features were subsequently judged to be of minor importance to the gross ecological picture in comparison with changing river temperatures and discharges.

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 in 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. A substantial population of adult fall chinook now spawns each fall in the Hanford environs (Watson, 1970). The progeny of these adults reside in the river each spring and early summer before migrating seaward (Mains and Smith, 1964; Becker 1970b). Other young salmonids

duced 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 actors 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 occur 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, being lowest in January and February, rising during the spring, and peaking 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 93 km free-flowing river. From the standpoint of thermal requirements of juvenile chinook, temperatures were well below the thermal referenda of 12-14°C established by Brett (1952) in March and April when most fry emerged from the gravel. Temperatures enter the preferred range in May and early June, where conditions are presumably 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

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FIGURE 1. TEMPERATURES AND FLOWS IN THE CENTRAL COLUMBIA RIVER DURING THE SPRING AND SUMMER OF 1969, IN RELATION TO THE PRESENCE OF JUVENILE CHINOOK SALMON, THEIR PREFERRED TEMPERATURE RANGE AND THEIR OPTIMUM GROWTH RANGE (HATCHERY PRODUCTION).

the thermal tolerance of juvenile chinook in the Columbia appears to be somewhat below this level. Temperatures about 20°C, and above, may be considered suboptimum for young chinook because of high metabolic requirements and excessive expenditure of energy.

The annual range in river flow volumes in the central Columbia 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, increased flows occurred about 6 weeks earlier than usual because of operational releases at massive Grand Coulee Dam far above Hanford. 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 do not adequately reveal the extent of weekly and daily fluctuations in river discharges that occur from flow regulation at Priest Rapids Dam immediately above Hanford. 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 daily. During the annual spring spate, river water in excess of reservoir capacity is discharged over spillways at Priest Rapids. Weekly fluctuations at this time are less variable than during the summer and winter when greater need to conserve available water in the reservoir exists. Summer flow regulation may result in changes of the river level at the sampling stations of up to 8 feet in a 24 hr period.

As indicated in Figure 1, the maximum period of abundance of juvenile chinook in the Hanford area occurs from late March

to mid-July. During this period, the fish hatch and leave the gravel; some migrate seaward immediately while others assemble in shoreline areas for indeterminate periods of feeding and growth before departing. It is theorized that the combination of maximum river temperatures and minimum river flows function to impel most fish remaining at Hanford seaward by the end of July (Becker, 1970b).

FOOD COMPOSITION AND FEEDING ACTIVITY

Food Composition

A summary of organisms consumed by juvenile chinook at all sampling stations 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 (including zooplankton) were inconsequential. The forms included adult, subadult and larval stages of semiaquatic insects, various developmental stages of aquatics, and winged adults of the terrestrials. The groups of insects utilized were essentially similar in proportion during both years, thus revealing no major changes in food habits or availability of food organisms.

The Tendipedidae, or midge, was the dominate 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. High utilization reflects the widespread distribution and abundance of the Tendipedidae in aquatic habitats. When subadults emerged, rising to the surface of the river to take flight, they were

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

Food Item	1968		1969	
	Number	%	Number	%
INSECTA				
DIPTERA				
<u>Adults</u>				
Tendipedidae ⁽¹⁾	5,973	63.5	11,062	58.2
Dolichopodidae	31	0.3	6	--
Emphididae	13	--	4	--
Simulidae	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	--
Emphididae	0	--	1	--
Simulidae	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. (contd)

Food Item	1968		1969	
	Number	%	Number	%
HEMIPTERA				
Notonectidae	248	2.6	918	4.8
Mesovelidae	34	0.4	2	--
Macrovelidae	1	--	0	--
Corixidae	1	--	1	--
Saldidae	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	3	--	187	1.0
<u>Larvae</u>				
Unidentified	0	--	21	0.1

Table 2. (contd)

Food Item	1968		1969	
	Number	%	Number	%
TRICHOPTERA				
<u>Adults</u>				
Hydropsychidae	277	2.9	948	5.0
Psychomyidae	0	--	3	--
Calamoceratidae	0	--	6	--
Hydroptilidae	0	--	12	--
Unidentified	1	--	44	0.2
<u>Larvae</u>				
Hydropsychidae	18	0.2	93	0.5
Psychomyidae	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>				
	0	--	0	--
<u>Subimagos</u>				
<u>Unidentified</u>				
	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>				
<u>Unidentified</u>				
	26	0.3	27	0.1

Table 2. (contd)

Food Item	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	--
Unid. adults	0	--	98	0.5
Unid. 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 (2)	0.3	15 (2)	0.1
Nematoda	7	--	11	--
Algae	1 (3)	--	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. Number of fish containing small quantities of Cladocera, Ostracoda, Copepoda, or Amphipoda.
3. A quantity of Anacystis.

readily captured by feeding chinook in the Hanford area (64% in 1968, 58% in 1969). Worm-like midge larvae, without protective tubes and thus apparently adrift in the water, were utilized less extensively (17% in 1968, 18% in 1969).

The order Diptera, dominated by the Tendipedidae, provided 83 and 78% of all insects utilized in 1968 and 1969, respectively. All other insect orders were of secondary importance in terms of numbers but not necessarily volume or nutrition, since sizes of different species vary considerably. The relatively large Trichoptera, or caddisflies, (primarily Hydropsyche cockerelli) was numerically the second most important order. As with the midges, most caddisflies eaten were winged adults associated with the water-surface interface. (Larval caddisflies, though abundant, were presumably protected from chinook predation by sheltered habitats below stones.) Other orders of importance were the Hemiptera, primarily small Notonecta nymphs, and the Collembolla, or springtails, both commonly found at water-shoreline interface.

Very few Ephemeroptera (mayflies) and no Plecoptera (stoneflies) occurred in the stomach contents. These forms are occasionally important in the diet of salmonids in other streams. Unpublished data from limited bottom samples, sporadic drift samples, 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

The possibility of a seasonal shift in the diet of juvenile chinook, which showed a relationship to the size of the fish

but was not clearly defined, was noted in 1968 (Becker, 1970a). Additional data were obtained in 1969. The proportion of major insect groups utilized each month is listed in Table 3, and the sizes of all fish representing monthly collections are illustrated in Figure 2. The mean number of insects per feeding fish showed an increasing trend from March through July, in correlation with growth. Diptera (i.e. Tenthredinidae) were heavily utilized each month, with the greatest proportion of minute larval midges taken in early spring when the fish were small. Hemiptera (i.e. Notonecta nymphs) and Collembolla, both small forms, attained maximum utilization during the period of rising river volumes (Figure 1) when water inundated shoreline areas. Large adult Trichoptera were taken primarily in June and July. Seasonal use of adult caddisflies may be attributed to natural selection of large food organisms by growing fish as well as to seasonal abundance of the univoltine populations during their main period of metamorphosis and emergence.

Early Diet of Fry

Chinook fry are relatively small (35-40 mm FL) when they emerge from the gravel of the riverbed. Apparently, many of these fish are swept directly downriver thereby giving rise to the early "migration" of fry noted by Mains and Smith (1964). The stomachs of 25 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 incompletely absorbed yolk sacs. The transitional period when young salmonids leave the gravel and commence active feeding is generally considered to be a critical phase in combination with the development of swimming ability. The data reveal

Table 3. Monthly Changes in Feeding Habits of Juvenile Chinook at Hanford in 1969, All Sampling Stations Combined (in percent).

Category	Percent Consumption Per Month				
	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 ($\pm$)	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.

27

8
A
1
0

FIGURE 2. LENGTH FREQUENCY DISTRIBUTIONS OF JUVENILE CHINOOKS COLLECTED AT HANFORD, 1969. (SMOOTHED BY A SHIFTING MEAN OF 3'S; INCLUDES FISH MEASURED IN EXCESS OF THOSE EXAMINED FOR FOOD CONTENTS.)

that feeding often started before the yolk was completely absorbed, when temperatures were low, and that food organisms in March and April were predominately small forms. Emerging adult and larval Tendipedidae (Table 3) were the major food components of the small fish.

Influence of Drift Organisms

Invertebrate drift in rivers and streams is now acknowledged to be an important phenomenon influencing the food and feeding activity of many freshwater fishes (Waters, 1969). Consideration of the developmental stages and biology of 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 capture of most Tendipedidae and Trichoptera, Hemiptera nymphs, and Collembola, the four principle insect groups utilized. Relatively few insect forms that normally adhere to epibenthic substrates or live within the gravel interstices were found.

Although semiaquatic and aquatic insects predominated in the stomach contents, some terrestrial forms were ingested. The orders Homoptera, Lepidoptera, Hymenoptera and Thysanoptera were almost entirely of terrestrial origin, and other terrestrials occur among the adult Diptera and Coleoptera (Table 2). Assuming that most of the "adult" midges and adult caddisflies were seized while emerging and on the surface film, the remaining true terrestrial insects comprised less than 4% of total food organisms. The aquatics and terrestrials formed separate endogenous and exogenous components of the drift, but the majority of insects utilized by juvenile chinook clearly originated within the river ecosystem.

ANALYSES FOR POTENTIAL THERMAL EFFECTS

Evaluation of possible effects resulting from heated effluents on the food and feeding of juvenile chinook in the Hanford environs was based on samples obtained at three stations situated above the discharge areas ("cold water" stations) and three below ("warm water" stations). Since feeding areas occurred along the shore, the warm water stations were not directly exposed to thermal increments from the midriver discharge plumes. Thus temperatures at the warm water stations were, at the most, only a few degrees above temperatures of the river above Hanford except for Station D, which received heated effluent from intragravel seepage in early spring. All stations received some warming from solar radiation during sunny days, particularly the backwater and slough areas. Heat increment from reactor and solar sources varied at each station with the stage of ambient water level, which affected current patterns and mixing with the cooler water in the main channel.

Analyses of data to detect any thermal effects, therefore, was conducted on the basis of rather general aspects. Two broad approaches were made. First, by comparison of parameters dealing with food and feeding and, second, by comparison of parameters dealing with growth.

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

Groups of fish at each station appeared to vary as a result of rapid turnover. Chinook from the cold water stations presumably had little previous exposure, directly or indirectly, to effluent discharges since the direction of fish movement in a large river like the Columbia is primarily downstream. It is assumed that fish from the warm water stations may have been subject to added heat from effluent discharges, but there was no way to determine 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. Adult Hydropsche were taken primarily at Stations B (9.2%) and C (7.2%), both with rubble bottoms and partially exposed to flows 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 (but then closed down), 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

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

Insect Group	Cold Water Stations ⁽¹⁾				Warm Water Stations ⁽¹⁾			
	A	B	C	Total	D	E	F	Total
11 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
11 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
11 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
11 "adults" ⁽²⁾	73.0	67.3	64.4	70.3	91.5	82.7	76.1	84.5
11 "larvae" ⁽³⁾	27.0	32.7	35.6	29.7	8.5	17.3	23.9	15.5

1. Cold and warm water 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.

re low at this site. However, adult Tendipedidae were undant in the stomach contents of fish collected at Station D, dicating that the flying adult midges were attracted to the rmed water in early spring when water (and air) temperatures mained fairly low.

As a whole, proportions of adult midges were higher 4.4 versus 41.3%) and larvae midges were lower (13.5 versus .6%) at warm water stations than at cold water stations. is suggests that the rate of metamorphosis of the Tendipedidae is increased by thermal addition. However, this is likely a urious correlation. In the absence of demonstrable effects om effluent discharges, proportional variations between ations (except for Station D) were assumed to result argely from intersite features, including (but not necessarily stricted to) type of substrate and extent of exposure to rrent flow.

Since intersite variations appeared to occur independently thermal effects, statistical comparisons of food organisms a purely numerical basis was considered to be irrelevant. n addition to variations between and within stations, the mber and types of insects eaten deviated widely between ndividual fish in each collection.

Feeding Activity

Table 4 suggests that some difference in feeding activity, n the basis of stomach contents, may exist between combined mples collected at all cold and all warm water stations. A esirable statistic to compare 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 most 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 used here primarily 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 entire 1969 season are presented in Table 5. Since $r' = +0.95$, there was a strongly positive relationship over the entire season. Monthly comparisons are illustrated in Figure 3. (March is omitted due to lack of samples from cold water 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 discharges were not only utilizing the same kinds of food but that the relative proportion of these foods remained essentially similar throughout the spring.

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

Food Item	Category	Cold Water Stations		Warm Water 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

$n = 8$

$\Sigma d = 0$

$\Sigma d^2 = 6$

$r' = +0.95$

1. Monthly comparison of r' are shown in Figure 3.

P. 29²⁰

COLD WATER STATIONS WARM WATER STATIONS

COLD WATER STATIONS WARM WATER STATIONS

FIGURE 3. RANK CORRELATION COEFFICIENTS (r') FOR MAJOR FOOD ITEMS INGESTED BY JUVENILE CHINOOKS EACH MONTH AT COLD AND WARM WATER STATIONS. (A = INSECT ADULTS, B = INSECT LARVAE, C = TENDIPEDIDAE ADULTS, D = TENDIPEDIDAE LARVAE, E = HEMIPTERA, F = HYDROPSYCHIDAE ADULTS, G = HYDROPSYCHIDAE LARVAE, H = COLLEMBOLA.)

Mean Insects Per Feeding Fish

The mean numbers of insects per stomach of feeding fish are summarized in Table 6. Numbers at all stations revealed a general increase from March to July, in correlation with both increasing water temperatures and size of the fish. During March and April, when river temperatures were low ($3-9^{\circ}\text{C}$) 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 Collembola 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 $16-20^{\circ}\text{C}$ and the fish were attaining maximum size.

High variations within and between samples precluded meaningful statistical comparison between cold and warm water stations on the basis of mean numbers of insects per stomach. Although slightly higher means were recorded for cold water stations (29/fish) than at warm water stations (25/fish) this has little practical significance. One cold water station (A) and one warmwater station (F), both slough-like areas, provided the greatest amount of food organisms.

Juvenile chinooks 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 ($3-5^{\circ}\text{C}$). In 1968, mean numbers of insects per fish at Station D were found to be low in early May in comparison with other stations. 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 6). The length

Table 6. Mean Numbers of Insects Per Stomach of Feeding Chinook at Cold Water and Warm Water Stations, 1969. (Number of fish examined in parentheses.)

Month	Cold Water Stations				Warm Water 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 warm water stations were located above and below the heated effluent discharges, respectively.

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

frequency distribution of fish collected in March (Figure 2) was based entirely on individuals collected at Station D; growth of this early group appeared to be rapid because fish lengths greatly exceeded those of fish collected in April at other stations.

On the basis of Table 6, 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 cold and all warmwater stations on each sampling date is illustrated in Figure 4. 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). Numeral (a) on Figure 4 reflects high consumption of *Collembolla* on 20 May (Station A), while numeral (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 in size from minute midges to large caddisflies; a fish can contain large numbers of small insects that still would not equal a few large insects in terms of energy supplied. Second, stomach contents reveal only feeding at the approximate time a sample was taken and not the preceding feedings that were responsible for growth. Third, 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

FIGURE 4. NUMBERS OF INSECTS PER STOMACH CONTENT IN RELATION TO SIZE OF JUVENILE CHINOOKS FROM COLD AND WARM WATER STATIONS, MARCH-JULY 1969. (DATA ARE MEANS BASED ON SUCCESSIVE SAMPLING DATES.)

Columbia (Figure 1). Fourth, changes in the water levels influence current patterns, the available food supply, and, more or less, the expenditure of energy required for a fish to obtain a "full meal".

Seasonal Increases in Fish Length

Growth of juvenile chinook, as revealed by consecutive samples at each station from March to July, is illustrated in Figure 5. Growth (sample means) was relatively slow and uniform at each station during April and early May when mass emergence from the gravel and recruitment to shoreline zones was initiated. Variations in mean sample lengths appeared with further growth in late May, and became extreme within and between stations in June and July. These variations clearly suggest a rapid turnover at each station, as might be expected in a population composed of transitory groups. 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 all 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 7. The test supports deductions made from Figure 5 by demonstrating significant differences between sample means, particularly in late May, June, and July. Since the sample means within and between stations differed widely, statistical comparison of grouped means from cold

FIGURE 5. GROWTH OF JUVENILE CHINOOK SALMON COLLECTED FROM THREE STATIONS ABOVE THE HANFORD EFFLUENT DISCHARGES (COLD WATER) AND THREE STATIONS BELOW (WARM WATER), MARCH-JULY 1969. (DATA ARE MEANS ON SUCCESSIVE SAMPLING DATES)

(Data are means on successive sampling dates)

Table 7. Summary, Statistical Comparison of Sample Mean Lengths by Duncan's Multiple Range Test (Within Cold and Warm Water Stations).

Date	Warm Water 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 <u>A</u>	39.70 <u>B</u>	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	Cold Water 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.

and warm water stations would probably be meaningless. Instead, comparison was made on the basis of length-weight relationships in the following section.

A clearer picture of growth in relation to seasonal increases in river temperatures, however, is shown in Figure 6 where the means lengths of all juvenile chinook collected at the cold and warm water stations are compared. The slight curvilinear relationship indicates, as might be expected, that increased growth rates occurred 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 cold and all warm water stations (irrespective of time), as illustrated in Figure 7. 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 both station categories. Both biological and statistical considerations indicated the use of a nonlinear least squares 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 by using the power function. Thus proportionate allometric development was a conclusion consistent with all data. Length-weight relationships of juvenile chinook collected at all cold and all warm water stations were approximately equal.

TEMPERATURES (°C)

20

15

10

5

JULY

JUNE

MAY

APRIL

MARCH

COLUMBIA RIVER TEMPERATURES

COLD WATER STATIONS (n=237)

WARM WATER STATIONS (n=459)

RICHLAND

PRIEST RAPIDS

FORK LENGTH (MM)

FIGURE 6. GROWTH OF JUVENILE CHINOOK SALMON COLLECTED AT COLD AND WARM WATER STATIONS, MARCH-JULY 1969, IN RELATION TO TEMPERATURE. (GROWTHS ARE MEAN LENGTHS ON SUCCESSIVE SAMPLING DATES; TEMPERATURES ARE WEEKLY MEANS.)

FIGURE 7. LENGTH-WEIGHT RELATIONSHIPS OF YOUNG CHINOOK FROM COLD AND WARM WATER STATIONS, MARCH-JULY 1969. (DATA ARE MEANS ON SUCCESSIVE SAMPLING DATES.)

Coefficients of Condition

Since no significant differences appeared in statistical comparison of 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 cold and all warm water stations. 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 8. 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 just beginning to feed at low temperatures. Q was nearly similar for the larger size groups at both cold and warm water stations, ranging from 1.29 to 1.39. No major difference was evident, even for the larger fish dwelling and feeding for the longest period of time under somewhat dissimilar thermal conditions above and below the effluent discharges.

Dry Weight of Stomach Contents

The dry weight of stomach contents reflects feeding intensity in the habitat only within a short time preceding

Table 8. Mean Lengths, Mean Weights and the Coefficient of Condition (Q) for Different 10 mm Size Groups of Juvenile Chinook Salmon Collected at Cold and Warm Water Stations, March-June 1969.

Size Group (1)	Cold Water Stations				Warm Water 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.

collection. Digestion, metabolic rates, and energy expenditure increase with a rise in river temperature. All samples in this study were collected during the day and, except for some fry that contained remnants of the yolk sac, all fish contained some food organisms. Extreme variations between and within samples, however, precluded meaningful statistical comparison between cold and warm water stations on the basis of food biomass. (The same variations were evident in comparing mean number of insects per feeding fish.)

Nevertheless, dry weight of stomach contents provides an indication of feeding activity that changes with growth of the fish as temperatures increase 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 food biomass by combining means at all cold and all warm water stations throughout the season is given in Figure 8. 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 weight of stomach contents were minimum in April, when mass 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.

The mean dry weight of stomach food in relation to mean size of fish collected on different dates at all cold and all warm water stations is illustrated in Figure 9. Food biomass increased rapidly with size, but the relationship was not strictly linear because of variations even between the grouped

FIGURE 8. SEASONAL CHANGES IN DRY WEIGHT OF STOMACH CONTENTS OF JUVENILE CHINOOK SALMON FROM COLD WATER AND WARM WATER STATIONS, MARCH-JULY 1969. (DATA ARE MEANS ON SUCCESSIVE SAMPLING DATES.)

90%

FIGURE 9. DRY WEIGHT OF STOMACH CONTENTS IN RELATION TO SIZE OF JUVENILE CHINOOK SALMON FROM COLD WATER AND WARM WATER STATIONS, MARCH-JULY 1969. (DATA ARE MEANS BASED ON SUCCESSIVE SAMPLING DATES.)

samples. Statistical comparison between samples collected at all cold and all warm water stations was made by calculating regression lines with the standard equation:

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

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.

Regression lines between cold and warm water stations differed significantly. Contained food biomass apparently increased more rapidly with fish size at cold water stations than at warm water stations. However, the slope for warm water stations was lowered by the final sample of largest fish 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

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 volumes. Living in strong currents and turbulent flow 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 eddys. 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 deeper water would not be detected.

Production of aquatic insects is known to vary widely among various types of substrate and even within a given type of substrate. However, considerable 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. Insects in the drift are produced in upriver areas as well as at each station, and therefore form a food complex presumably originating from several substrate types. The significance of invertebrate drift to stream fish is the effect 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 a sampling station downriver per unit of time is high than under low conditions because of the increased discharge (Waters, 1969).

Drift organisms often exhibit diel periodicities because many taxa are night active, and this phenomena may have influenced food and feeding of young chinook at Hanford. Since my samples were entirely collected during daylight hours, the data reflect feeding at this time. 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 three insect orders Ephemeroptera, Plecoptera, and Trichoptera; and the family Simuliidae of the 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 of similar availability during the day than they were at night.

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, 1942b; 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. On this basis, it was assumed that feeding corresponded roughly to food organisms occurring in the river drift, but not necessarily in proportion to what was available. Some selectivity was evident in that small chinook fry utilized small midges, both adults and larvae, most extensively whereas larger fish tended to prey on large food organisms such as adult Trichoptera in June and July (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 and food utilized by larger fish can be very diverse (Mundie, 1969).

Since warmer temperatures increase metabolism, a greater number of insects must be consumed in order for growth of fish to continue 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). Tendipedid larvae and adults are individually low in nutritional value because of their minute size. Yet midges were utilized throughout the season by juvenile chinook at Hanford, and abundance compensated for their small size. The large adult caddisflies ingested in June and July provided high nutritional value at a time when

temperatures were high and more energy was required to maintain growth. (By dry weight, one adult Hydropsyche cockerelli was equal to 35 adult tendipedids).

The distinctive features of chinook feeding in the central Columbia appear to be fourfold: first, relatively few insect types were extensively utilized; second, the fish had a high dependence on drifting, floating, or swimming organic material; third, they visually selected moving objects; and fourth, they appeared to be opportunists to a large degree. These features are not necessarily unique among young salmonids (Mundie, 1969), but demonstrate a close dependence upon living components in the river ecosystem. At Hanford, utilization of suspended organisms may well reflect variations in river flow. The annual increase in discharge in April and May (Figure 1) inundated shoreline areas that were exposed the entire preceding winter. Recolonization of flooded inshore areas depends primarily upon insect larvae in the drift, (which may occur rapidly), and secondarily on 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 flooded and exposed shoreline areas. 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 Collembola, and the terrestrial Arachnida (spiders).

Effects of Thermal Discharge

The ecological aspects reviewed above, particularly river flows regulated by hydroelectric power demand, extend to evaluation of the effects of heated effluents on the food, feeding, and growth of juvenile chinooks in the central Columbia.

The main discharges occur at fixed subsurface locations in midriver, and the mixing zones extend downriver in relatively narrow bands. The horizontal distribution of the mixing zones widens at lower river flows, but the plumes remain well away from the banks even at minimum flows of 40,000 ft³/sec. Consequently juvenile chinook feeding in inshore areas are not directly exposed to midriver discharges. 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 sampling 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 warm water stations was not possible. It is ecologically significant that the difference in river temperatures at Priest Rapids and at Richland is relatively low, (Figure 1), and that at least part of the summer heat increment (1-2°C) is due to solar radiation on the free-flowing river.

Analysis of length frequency distributions of fish collected at each sampling station revealed considerable variation from week to week. Seaward migration apparently occurred

intermittently over the entire sampling period. For this reason, groups of fish available at each station were interpreted as being unstable and existing in dynamic equilibrium with recruitment from the gravel, direct seaward migration, and irregular downstream or upstream movements along the shore. Weekly and daily variations in river discharge induced at Priest Rapids Dam probably implemented population turnover by alternately flooding and exposing shoreline habitats. On this basis, "exposure" of fish to any effect of heated effluent discharges was largely temporary and was 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 population 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 chinook fry into Station D at a season when river temperatures were cold (3-5°C) and well below preferred levels (12-14°C) 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 in insects consumed within and between stations were extreme and presumably resulted in large part from intersite characteristics that influenced availability of different insects for consumption. No changes in feeding activity was evident between fish taken at the cold and warm water stations, even on a monthly basis, when food organisms were compared by nonparametric rank correlation coefficient (r_s) (Table 5, Figure 3). 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 6) as the fish increased in size and metabolism responded to warming temperatures. Increases in mean fork length of juvenile chinook were also variable within and between stations on successive sampling dates, particularly in late May, June, and July (Figure 5), and were indicative of population turnover. Growth tended to increase throughout the season as the river warmed (Figure 6).

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 as indicators of the effects of heated effluent on feeding of juvenile chinook than food parameters.

Statistical comparison of mean fish lengths between all samples revealed some small but significant differences (Table 7); these differences were assumed to be meaningless because of the wide variability between samples or successive dates (Figure 5). The length-weight relationships between chinook sampled at all cold and all warm water stations, when combined and tested by nonlinear least squares power function, revealed no significant differences (Figure 7) 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 8). For groups of coho and steelhead fry reared at different population densities in experimental channels (Frazer 1969), Q values were generally lower than calculated here for juvenile chinook (1.29 to 1.39 for 46-85 mm fish), although the three species are not strictly comparable. This suggests that food and feeding conditions in the central Columbia were quite favorable for growth. Data obtained by Benson (1954) indicated 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 species dropped rapidly under maximum temperatures of the summer and fall.

Comparison of dry weights of stomach contents of feeding chinook from cold and warm water stations, on the basis of fish length, differed only slightly when compared by regression analysis (Figure 9). This difference was not considered to be of practical importance.

Consideration of all data obtained in this study reveal no gross effects resulting from heated 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 discharge plumes occur in midstream and the effluents are well mixed with the receiving river water before reaching inshore feeding areas. There are inherent difficulties in evaluation of thermal effects in a river with the size and physical features of the central Columbia. Moreover, the field situation, in contrast to the laboratory, is subject to numerous uncontrollable natural variables. The transient nature of the fish populations at each station (influenced by weekly and daily fluctuations in river discharge volumes) and the availability of drift organisms as food are important ecological features affecting critical thermal evaluation.

In retrospect, it is evident that precise evaluation of thermal effects on food and feeding of young salmon in nature would be most feasible under semicontrolled conditions. These studies would require artificial channels that simulate the river ecosystem, receive known thermal increments, are naturally seeded by populations of aquatic insects, and are stocked with known numbers of fry.

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