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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[1]

by

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ABSTRACT

The relationship of thermal discharges from 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, i.e. 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 are presented for 1968 and 1969, 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 orginated in the river ecosystem.

Analyses to detect thermal effects were made on parameters dealing with food, feeding and growth compiled from fish collected at three sites above ("coldwater stations") and three sites below ("warmwater 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 variation between and within individual stations. No consistent differences attributable to thermal increments were evident. The lack of detectable effects is apparently due to 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, influenced by changes in regulated river discharge, and the availability of food organisms in the river drift were ecological factors affecting critical thermal evaluation _in situ_.

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C. D. Becker

INTRODUCTION

Field studies on the relationship of thermal discharges 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 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 to provide a firmer basis for evaluating potential 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 the effects of temperature on feeding and growth of salmonid fishes; (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 composition 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.

SOME RELATIONSHIPS OF TEMPERATURE TO 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 below.

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°C (50-60°F) by Burrows (1963). Brett (1952) also gave 25.1°C as the upper incipient lethal level (where 50% of the fish die 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 preferrenda (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. 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 thermal 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

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[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.

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). 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, 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 "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). Young centrarchids consume about three times as much food per day at 20° as at 10°C (Hathaway, 1927). 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 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 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 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 a few food organisms.) Insects represented by isolated chitinous head capsules,

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

	Number of Chinook Examined										Fish per Date
	"Coldwater" Stations(1)				"Warmwater" Stations(1)						
Date	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
	($\Sigma n_1 = 254$)				($\Sigma n_2 = 515$)						

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(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.

particularly larval Tendipendidae, 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 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 these were sampled more or less consistently (Table 1). Supplemental samples were scattered among four secondary stations (W, X, Y, Z). All samples 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 ft^3/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 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 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 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 established by 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 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 in the central Columbia may be somewhat below this level. Temperatures about 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 ft^3/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 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 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 8 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 period, the fish hatch and leave the gravel; some are carried downriver while others assemble in shoreline areas for indeterminant 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.

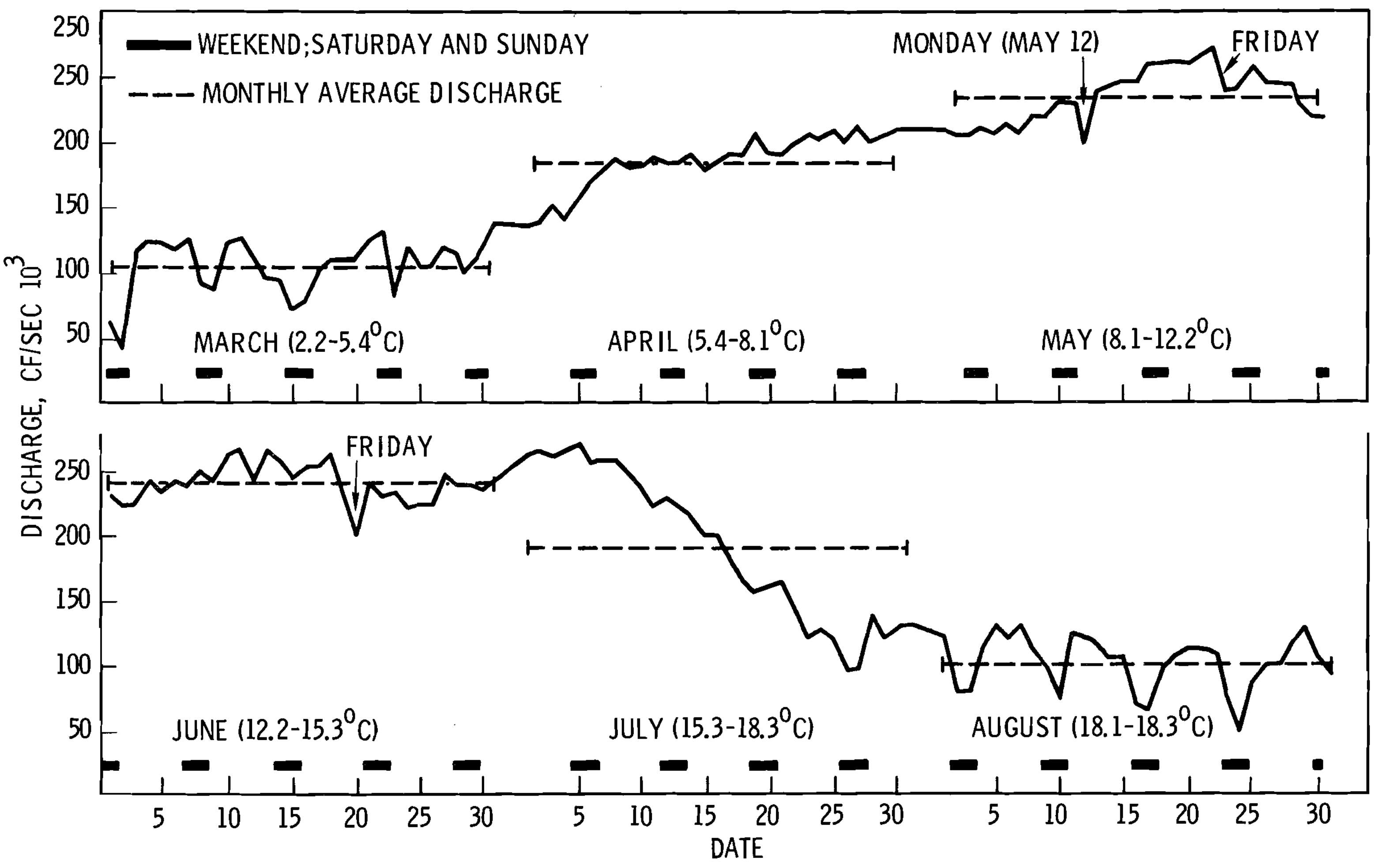

Figure 2. Daily fluctuations in Columbia River flows due to regulation at Priest Rapids Dam (above Hanford) in relation to the seasonal discharge cycle and monthly temperatures, March-August 1969.

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 (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 both years, thus revealing no major changes in fish food habits or availability of food organisms.

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. High utilization reflects the wide distribution and abundance of the Tendipedidae in aquatic habitats. When subadults emerged, rising to the surface of the river to take flight, they were readily captured by feeding chinook in the Hanford area (64% in 1968, 58% in 1969). Worm-like midge larvae, lacking protective tubes and thus apparently adrift in the water, were utilized less extensively (17% in 1968, 18% in 1969). But only a few of the normally attached midge pupae were taken.

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 Number	1968 %	1969 Number	1969 %
INSECTA				
DIPTERA				
Adults				
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	--
Ephydridae	1	--	3	--
Heleidae	0	--	1	--
Stratyomyidae	0	--	1	--
Dixidae	0	--	1	--
Unidentified	82	0.9	193	1.0
Larvae				
Tendipedidae	1,596	17.0	3,450	18.1
Dolichopodidae	18	--	4	--
Emphididae	0	--	1	--
Simulidae	55	0.6	54	0.3
Ephydridae	1	--	1	--
Heleidae	3	--	0	--
Muscidae	3	--	0	--
Unidentified	7	--	9	--
Pupae				
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 Number	1968 %	1969 Number	1969 %
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				
Adults				
Unidentified	4	--	23	0.1
Larvae				
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				
Adults				
Unidentified(2)	3	--	187	1.0
Larvae				
Unidentified(2)	0	--	21	0.1

Table 2. (cont'd)

Food Organism	1968 Number	1968 %	1969 Number	1969 %
TRICHOPTERA				
Adults				
Hydropsychidae	277	2.9	948	5.0
Psychomyidae	0	--	3	--
Calamoceratidae	0	--	6	--
Hydroptilidae	0	--	12	--
Unidentified	1	--	44	0.2
Larvae				
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				
Adults				
Subimagos	0	--	0	--
Unidentified	8	0.1	0	--
Nymphs				
Baetidae	1	--	24	0.1
Unidentified	0	--	4	--
TOTAL EPHEMEROPTERA	9	0.1	28	0.1
HYMENOPTERA				
Adults				
Unidentified	26	0.3	27	0.1

Table 2. (cont'd)

Food Organism	1968		1969	
	Number	%	Number	%
HOMOPTERA				
Adults				
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

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

The order Diptera, dominated by the Tendipedidae, provided 83 and 78% of the insects utilized in 1968 and 1969, respectively. All other insect orders were of secondary importance in terms of numbers but not necessarily in volume or nutritional values 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 their sheltered habitats below stones.) Other orders of importance were the Hemiptera, primarily small _Notonecta_ nymphs, and the Collembolla (springtails).

Few Ephemeroptera (mayflies) and no Plecoptera (stoneflies) occurred in the stomach contents. These forms are often important dietary items for 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 3. The mean number of insects per feeding fish showed an increasing trend from March through July, in correlation with growth. Diptera (i.e. Tendipedidae) 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, received maximum utilization during the period of rising river volumes (Figures 1, 2) 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). In support of this contention, 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, commence active feeding, and develop swimming ability is generally considered to be a critical phase. The data reveal

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

Food Organism	Consumption per Month (Percent) March	April	May	June	July
Insect Group					
*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
No. Fish Examined	46	275	160	199	89
Fish Size (mm)					
Mean	39.4	39.9	44.1	49.4	58.7
Standard Deviation ($\pm$)	2.8	2.3	4.8	7.7	11.2
$\overline{X}$ Insects/Feeding Fish	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.

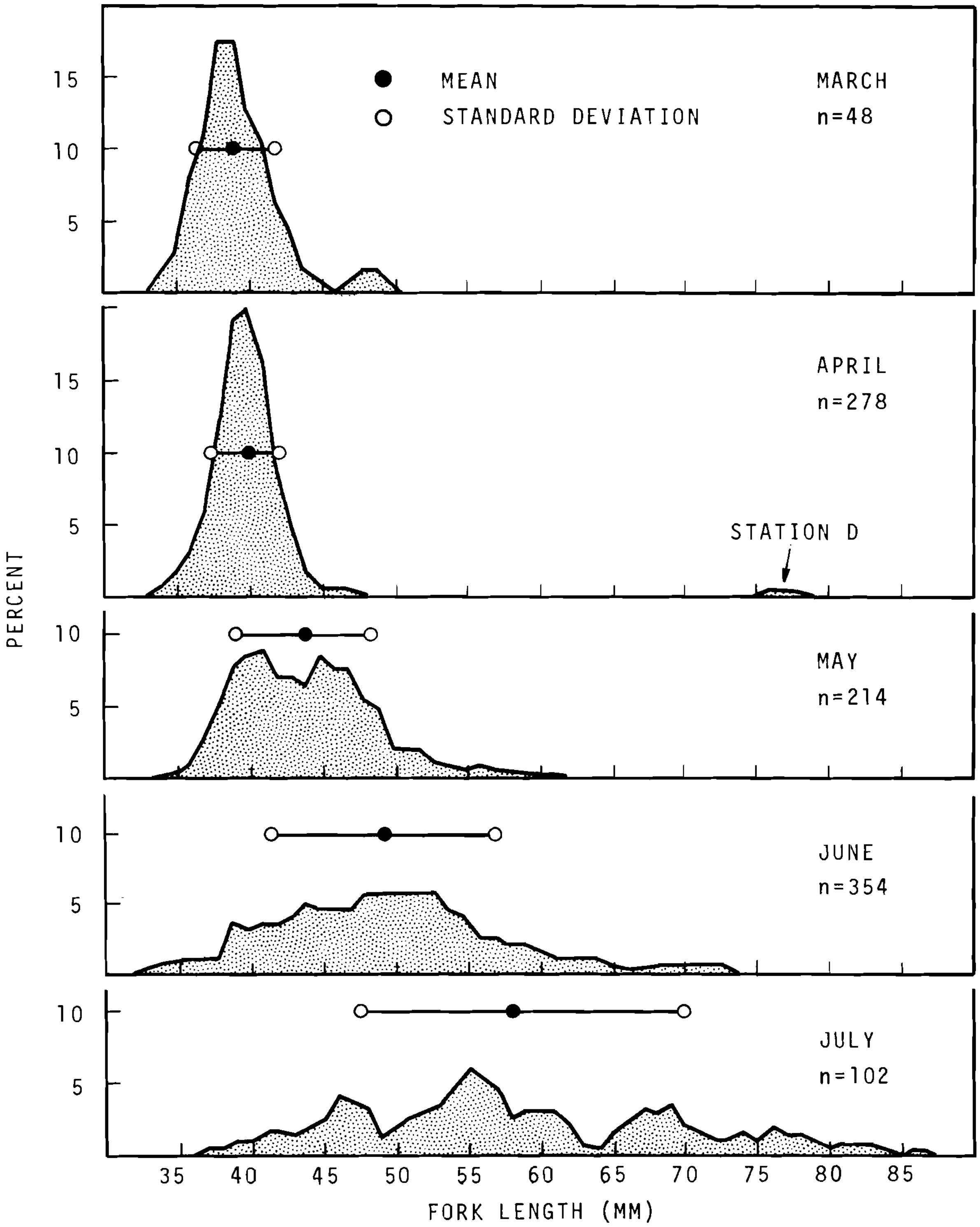

Figure 3. Length frequency distributions of juvenile chinook collected at Hanford, 1969.

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. Emerging adult and larval Tendipedidae (Table 3) were the major food components of fry.

Influence of Drift Organisms

Invertebrate drift in rivers and streams is 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 selection of most Tendipedidae and Trichoptera, Hemiptera nymphs and Collembola, the four main insect groups utilized. 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, Hymenoptera and Thysanoptera were almost entirely of terrestrial origin, and other terrestrials occur among the adult Diptera, Coleoptera and Lepidoptera (other than Pyralidae) (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 the total food organisms. Albeit aquatic and terrestrial insects form separate endogenous and exogenous components of the drift, however, the majority of insects utilized by juvenile chinook at Hanford clearly originate within the river ecosystem.

ANALYSES FOR POTENTIAL THERMAL EFFECTS

Evaluation of possible thermal effects on the food and feeding of juvenile chinook in the Hanford environs was based on samples obtained at three stations above the discharge areas ("coldwater" stations) and three below ("warmwater" stations). Since feeding areas occurred along the shore, the warmwater stations were not directly exposed to thermal increments from the midriver discharge plumes. Thus temperatures at the warmwater stations were, at the most, only a few degrees above temperatures in the river above Hanford. An exception was 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 in relation to ambient water levels, which affected current patterns and mixing with cooler water in the main channel.

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

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 coldwater stations above the reactors were assumed to have had no exposure to heated effluents, whereas insects at warmwater 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 coldwater 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 warmwater 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 Hydropsyche 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

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

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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.

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.

As a whole, proportions of adult midges were higher (64.4 versus 41.3%) and larvae midges were lower (13.5 versus 27.6%) at warmwater stations than at coldwater stations. This suggests that the rate of metamorphosis of the Tendipedidae was increased by thermal addition. Possibly true in theory, this is likely a spurious correlation. In the absence of demonstrable effects from effluent discharges, proportional variations between stations (except for Station D) must be assumed to result largely from intersite features, including (but not necessarily restricted to) type of substrate, extent of exposure to current flow, and possible feeding preferences between individual fish.

Since intersite variations appeared to occur independently of thermal effects, statistical comparison of food organisms on a numerical basis was considered 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.

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:

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

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 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 $r' = +0.93$, 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

Table 5. Comparison of Major Food Organisms Consumed by Juvenile Chinook Salmon 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.

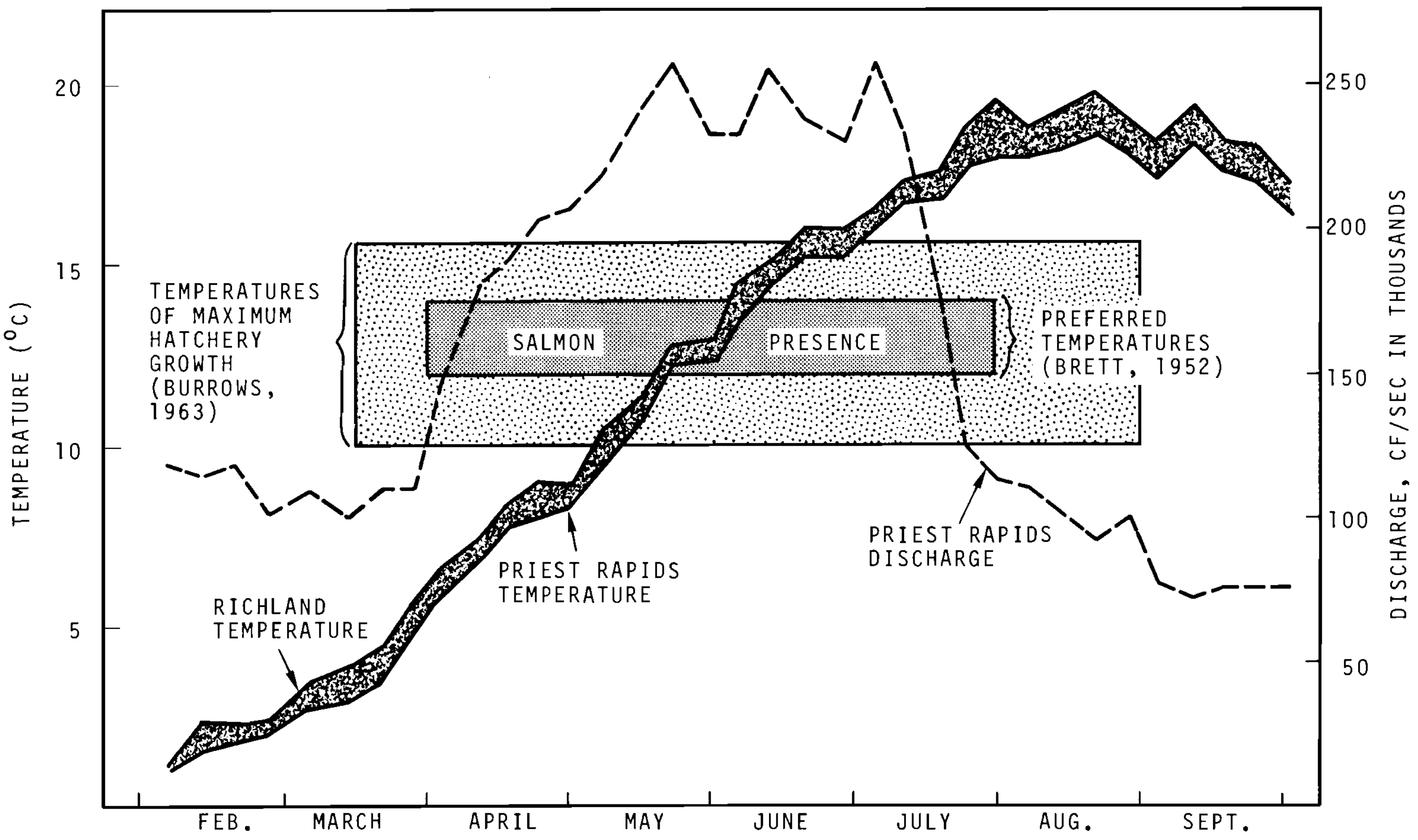


Figure 1. Temperature and flow in the central Columbia River during the spring and summer of 1969, in relation to the presence of juvenile chinook salmon, and their preferred temperature and optimum growth (hatchery production) ranges.

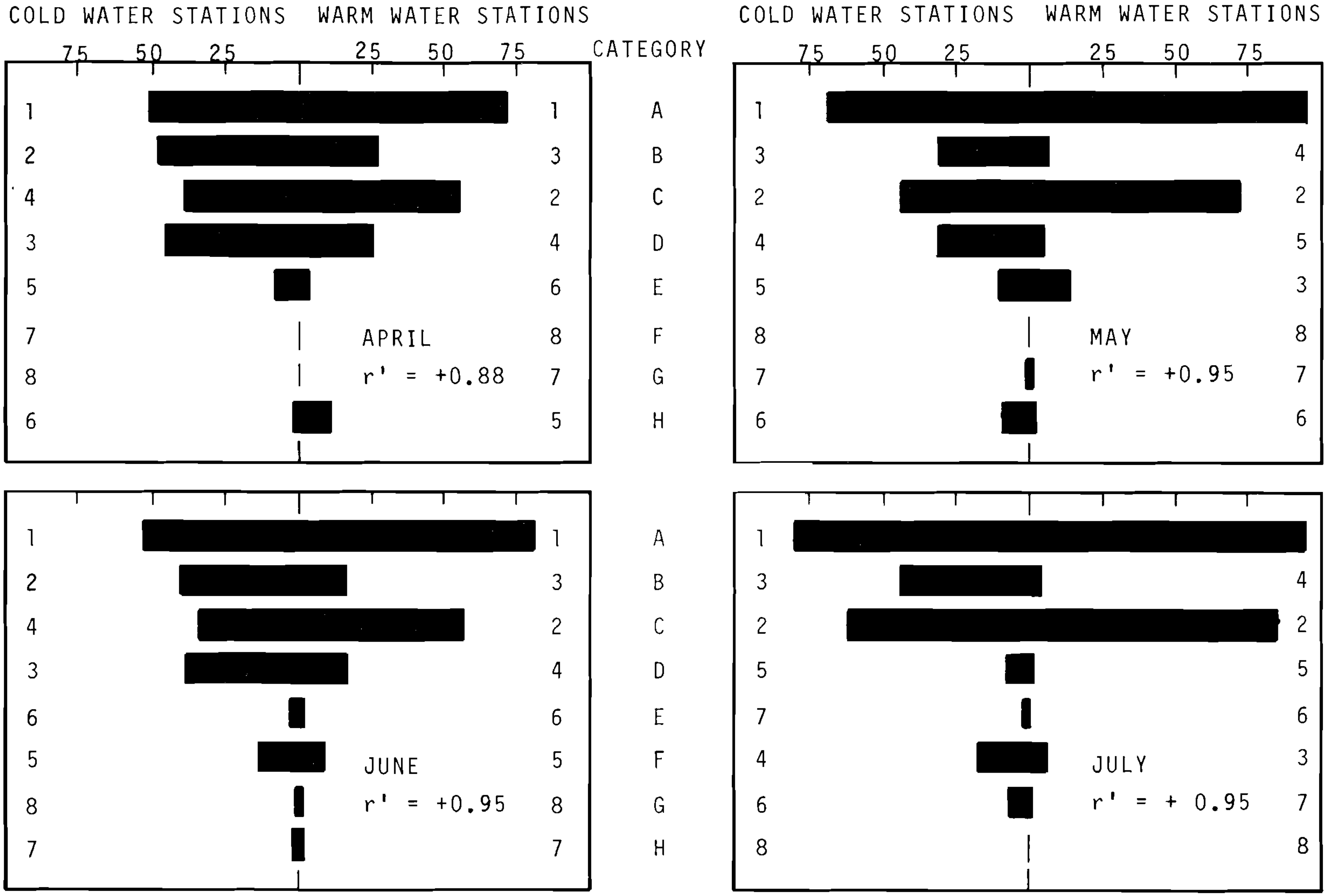


FIGURE 4. Rank correlation coefficients (r') for major food organisms ingested by juvenile chinook each month at cold and warm water stations.

heated discharges were utilizing the same kinds of foods. However, the relative proportion of these foods varied throughout the spring.

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 on the basis of relative proportions. To explore these differences more fully, the percentages of major food organisms in the stomach contents within and between stations were tabulated on a monthly basis (Table 6). Since the category "Diptera" corresponds 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:

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

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 of species populations.

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
	Station A				Station B				Station C				All Coldwater Stations			
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
	Station D				Station E				Station F				All Warmwater Stations			
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)

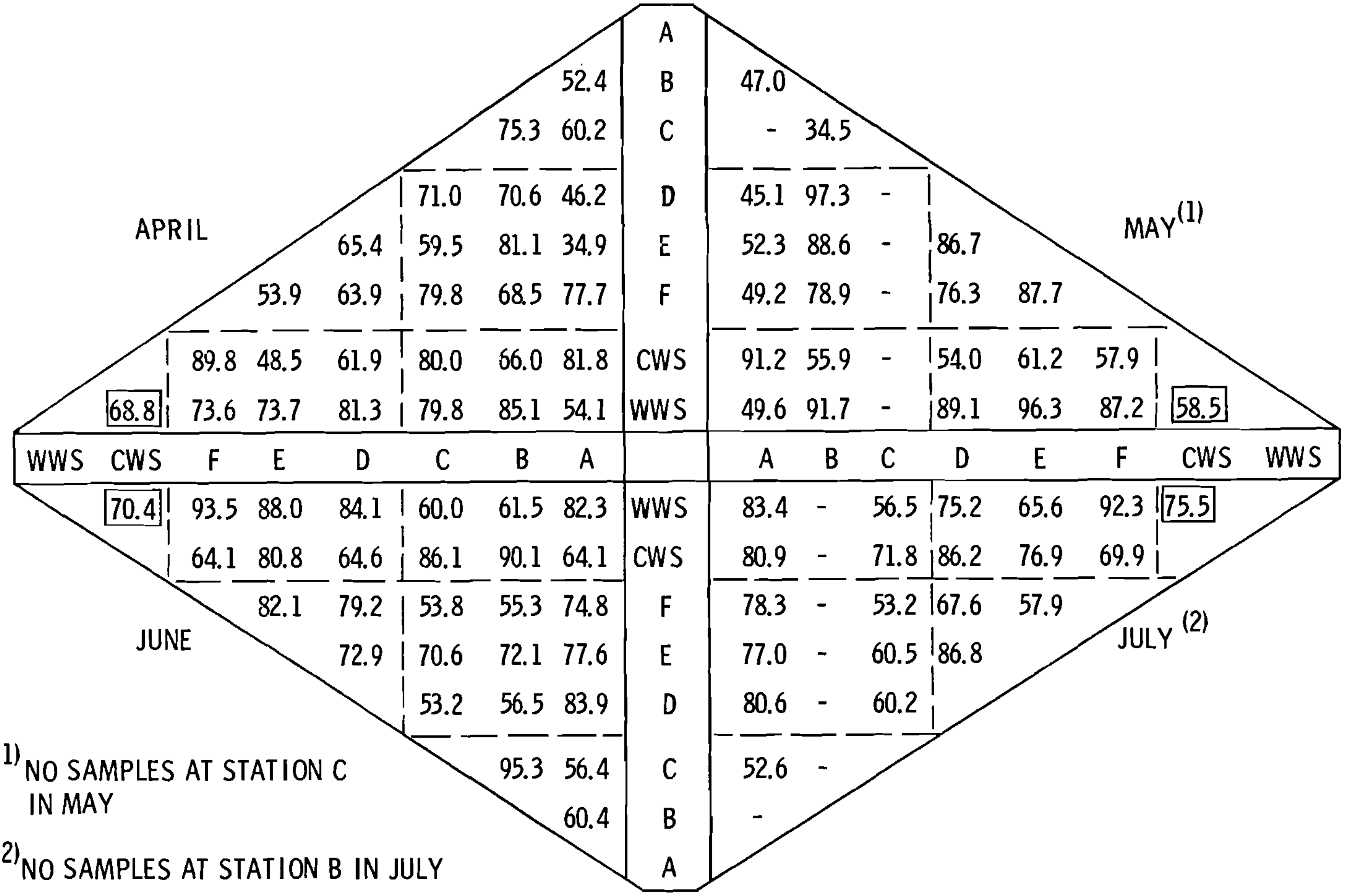
Food Organism	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July
Hydropsychidae																
Adults	0.0	0.0	12.2	17.4	0.0	0.0	7.7	26.9	0.0	0.0	1.1	3.2	0.0	0.0	7.2	6.8
Larvae	0.0	0.0	0.0	0.0	0.7	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.2	0.1
Collembola	26.1	4.1	2.2	0.0	4.9	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.

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

Percentage similarities (PS_c) for all possible combinations of samples were compiled and entered in a diamond matrix (Figure 5). Values of combined samples for all cold and all warmwater stations ranged from a low of 58.5 in May, 68.8 in April, 70.4 in June, to 75.5 in July (shaded areas). Thus the lowest similarity occurred in May, the greatest in July. Monthly computed figures within either cold or warmwater stations, or between them, ranged above and below these values. No consistent pattern was evident. A warmwater station (E, F, or G) sometimes showed a high similarity value when compared with a coldwater station (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 warmwater station subject to warm effluent via intragravel seepage



								A								
							52.4	B	47.0							
						75.3	60.2	C	-	34.5						
					71.0	70.6	46.2	D	45.1	97.3	-					
				65.4	59.5	81.1	34.9	E	52.3	88.6	-	86.7				
			53.9	63.9	79.8	68.5	77.7	F	49.2	78.9	-	76.3	87.7			
		89.8	48.5	61.9	80.0	66.0	81.8	CWS	91.2	55.9	-	54.0	61.2	57.9		
	68.8	73.6	73.7	81.3	79.8	85.1	54.1	WWS	49.6	91.7	-	89.1	96.3	87.2	58.5	
WWS	CWS	F	E	D	C	B	A		A	B	C	D	E	F	CWS	WWS
	70.4	93.5	88.0	84.1	60.0	61.5	82.3	WWS	83.4	-	56.5	75.2	65.6	92.3	75.5	
		64.1	80.8	64.6	86.1	90.1	64.1	CWS	80.9	-	71.8	86.2	76.9	69.9		
			82.1	79.2	53.8	55.3	74.8	F	78.3	-	53.2	67.6	57.9			
				72.9	70.6	72.1	77.6	E	77.0	-	60.5	86.8				
					53.2	56.5	83.9	D	80.6	-	60.2					
						95.3	56.4	C	52.6	-						
							60.4	B	-							
								A								

(1) NO SAMPLES AT STATION C IN MAY

(2) NO SAMPLES AT STATION B IN JULY

Figure 5. Diamond matrix comparisons of percent similarities (PS_c) between and within cold (A, B, C) and warmwater (D, E, F) stations based on major food organisms of juvenile chinook, April-July 1969.

in early spring. Compared with all coldwater stations (CWS - averaged data), the values were low in April (61.9), May (54.0) and June (64.6) and high in July (86.2). This may reflect gradual cessation of seepage after spring closure of the C reactor.

Mean Insects Per Feeding Fish

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 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 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°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 coldwater stations (29/fish) than at warmwater stations (25/fish), this had little practical significance. Feeding was most intense at one coldwater station (A) and one warmwater station (F), both slough-like areas.

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

	Coldwater Stations				Warmwater Stations						
Month	A	B	C	Total	D	E	F	Total	All Stations	Mean Size (mm)	Temp. Range (^{o}C)
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.

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 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 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 greatly exceeded those of fish collected in April 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 cold and all warmwater stations 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 Collembolla 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 in size from minute midges

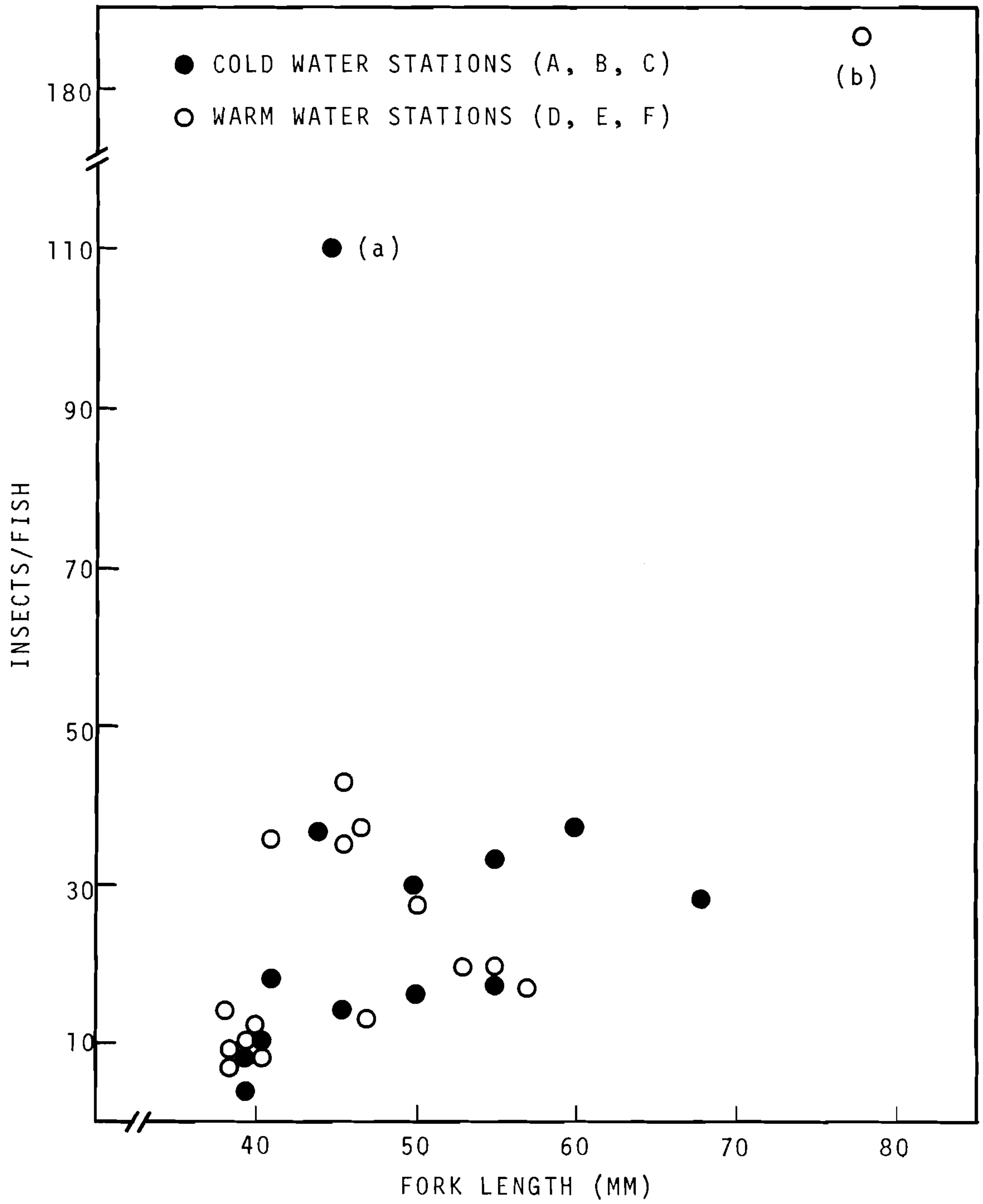


FIGURE 6. Numbers of Insects Per Stomach Content in Juvenile Chinook from Cold and Warm-water Stations, March-July 1969

to large caddisflies; a fish can 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 a March to July range of 3 to 20°C that occurs in the central Columbia (Figure 1). Fifth, 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 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 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

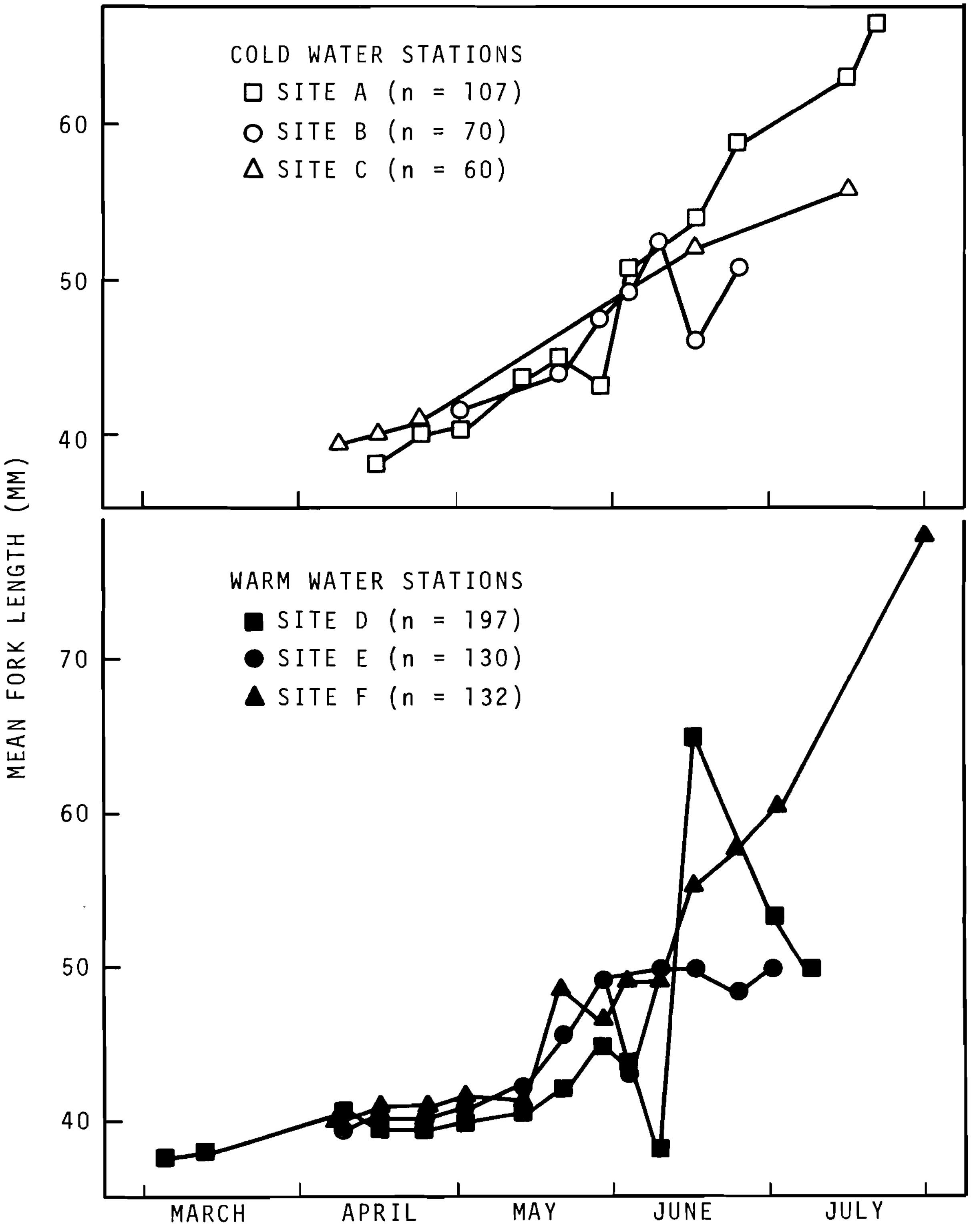


FIGURE 7. Growth of juvenile chinook collected from stations above (coldwater) and below (warmwater) the Hanford effluent discharges, March-July 1969.

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. Since sample means within and between stations differed widely, statistical comparison of grouped means from cold and warmwater stations 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 cold and warmwater stations are compared. The slight curvelinear relationship indicates, as 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 warmwater stations (irrespective of time), as illustrated in Figure 9. The relationship was essentially linear for young chinook of the 35-80 mm size range.

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) D	E	F	Group Mean	Number Fish	Standard Deviation
3/4	38.69	-----	-----	38.68	19	2.19
3/11	38.90	-----	-----	39.90	10	1.66
4/8	40.50 A	39.35 B	39.33 B	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 A	45.60 B	48.80 C	43.43	30	4.35
5/27	45.10	49.10	46.50	46.90	30	4.46
6/3	43.80 A	43.10 A	49.10 B	45.33	30	4.34
6/10	37.75 A	50.20 B	49.70 B	46.46	28	7.05
6/16	65.00 A	50.30 B	55.40 B	56.90	30	9.03
6/24	-----	48.60 A	58.00 B	53.30	20	8.05
7/2	53.60 A	49.70	60.60 B	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) A	B	C	Group Mean	Number Fish	Standard Deviation
4/8	-----	-----	39.65	39.65	20	1.90
4/15	38.40 A	-----	40.40 B	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 A	50.70 B	-----	54.95	20	9.54
7/15	63.40 A	-----	55.90 B	59.65	20	8.01
7/21	68.10	-----	-----	68.10	10	5.80

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(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.

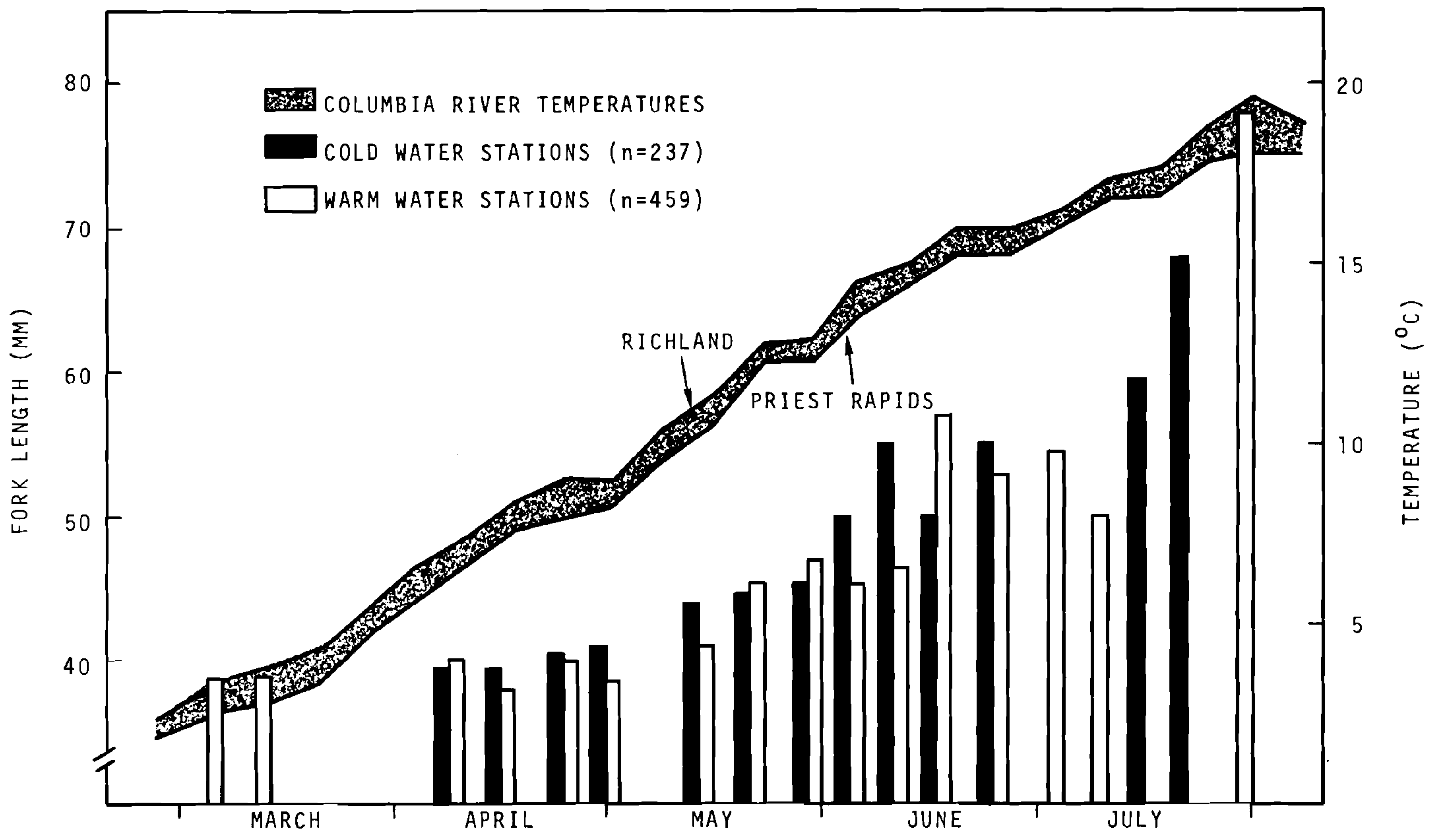

FIGURE 8. Growth of juvenile chinook collected at cold and warmwater stations, March-July 1969, in relation to Columbia River temperatures.

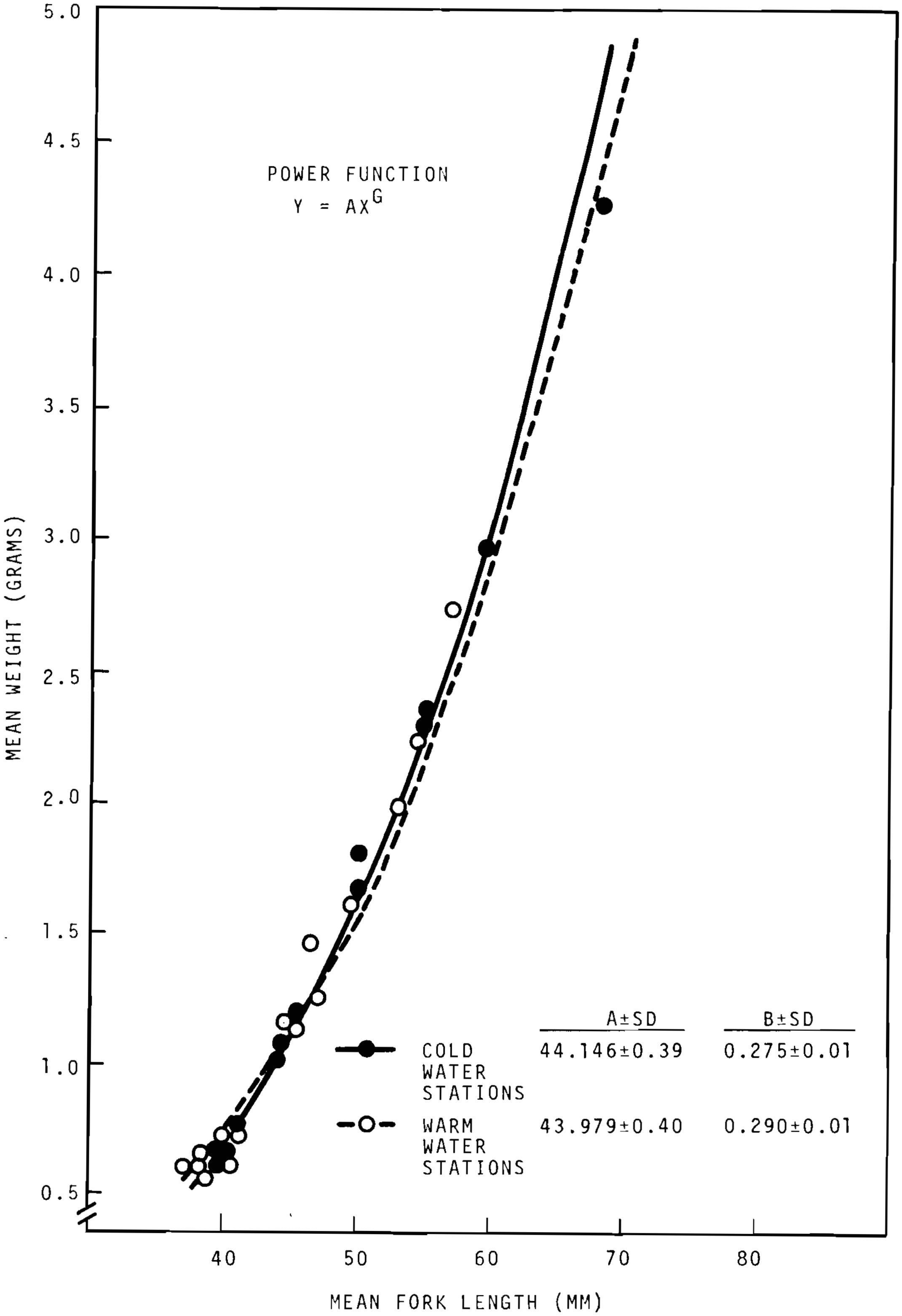

FIGURE 9. Length-weight relationships of juvenile chinook from cold and warmwater stations, March-July 1969.

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 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, and therefore proportionate allomeric development was a conclusion consistent with all data. Length-weight relationships of juvenile chinook collected at all cold and all warmwater stations were approximately equal.

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 warmwater 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 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 cold and warmwater stations, 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.

Dry Weight of Stomach Contents

The dry weight of stomach contents reflects feeding intensity in the habitat 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 the yolk sac, all fish contained some food organisms. Extreme variations between and within samples, however, precluded meaningful statistical comparison between cold and warmwater stations on the basis of food biomass. (Similar variations were evident in mean number of insects per feeding fish.)

Nevertheless, dry weight of stomach contents 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 food biomass by

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.

	Coldwater Stations				Warmwater Stations			
Size Group(1)	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.

combining means at all cold and all warmwater stations 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 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 food biomass in relation to mean size of fish collected at all cold and all warmwater stations is illustrated in Figure 11. Food biomass increased rapidly with size, but the relationship was not strictly linear because of variations even between the grouped samples. Statistical comparison between samples collected at all cold and all warm water stations (Figure 11) 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 warmwater stations differed significantly. Contained food biomass apparently increased more rapidly with fish size at coldwater stations than at warmwater stations. However, the slope for warmwater stations was lowered by the final sample of

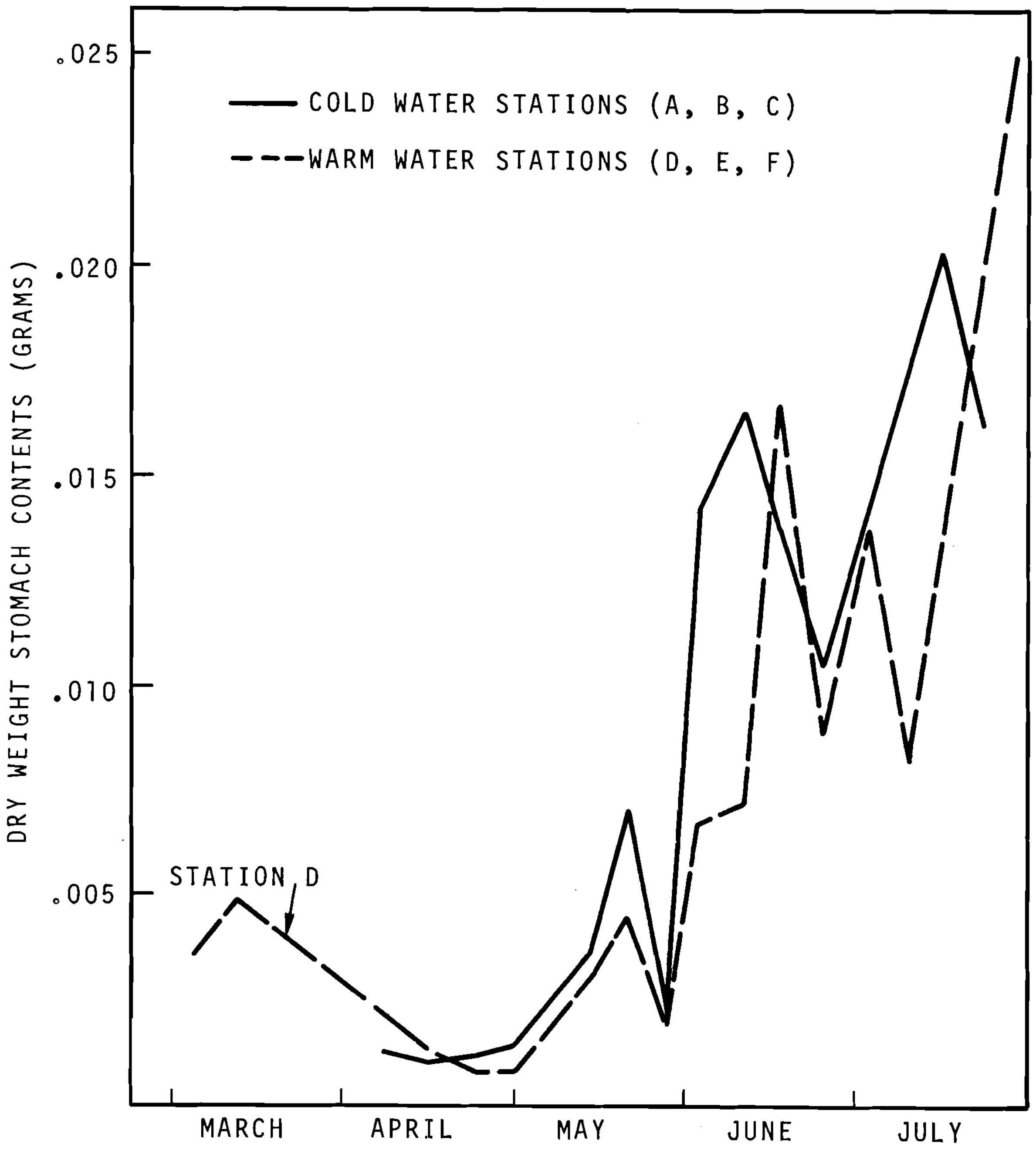

FIGURE 10. Seasonal changes in dry weight of stomach contents of juvenile chinook from cold and warmwater stations, March-July 1969.

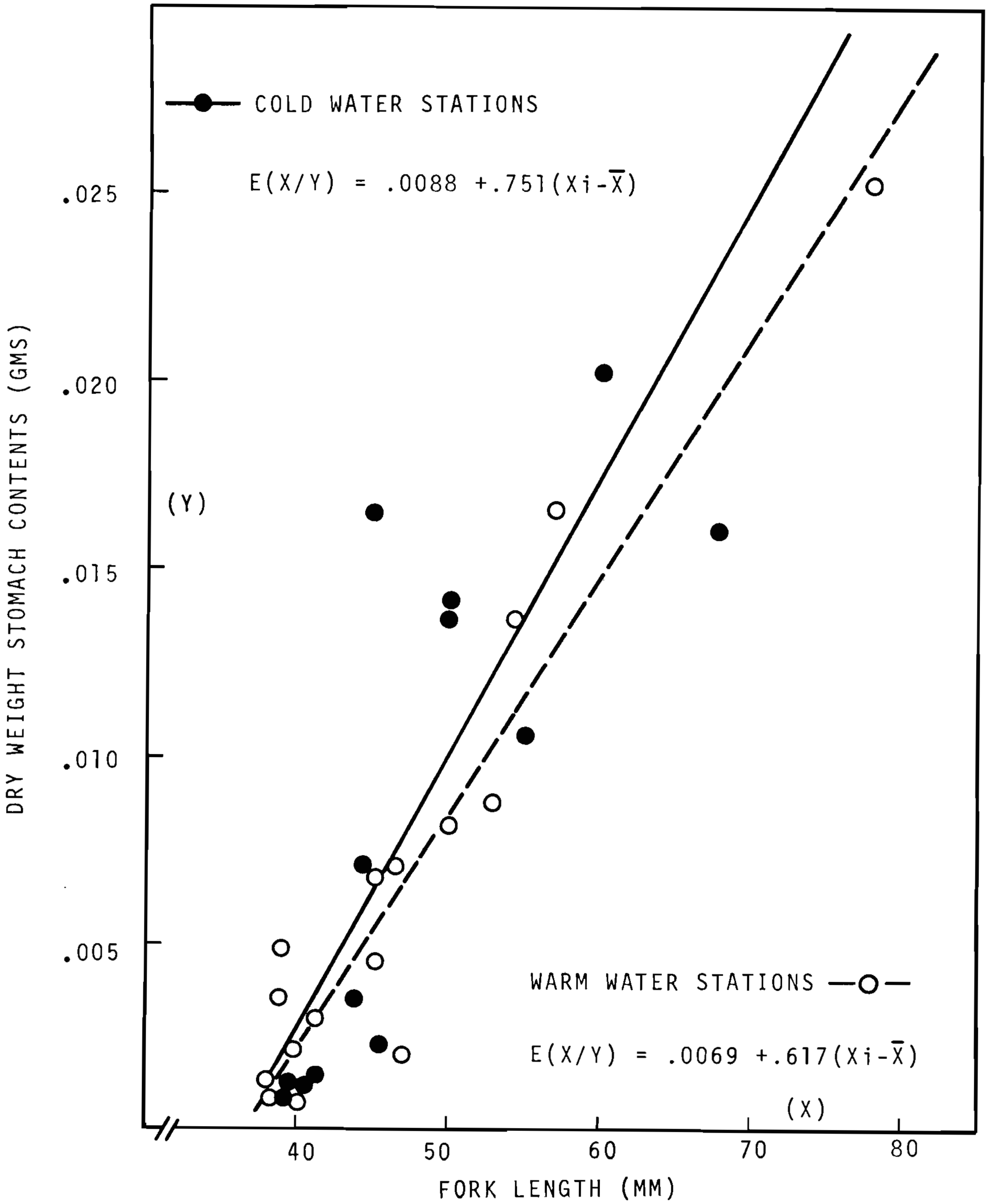

FIGURE 11. Dry weight of stomach contents in relation to size of juvenile chinook from cold and warmwater stations, March-July 1969.

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 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 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. salmon, trout and charr) reveal that insects, primarily aquatic but also terrestrial forms, are the predominant food organisms utilized in lotic habitats. Clemens (1934) also found that young chinook residing in 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 similar to those of young coho salmon (O. kisutch), a closely related species.

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. 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 tropic level, are in turn influenced by a complex of environmental factors particularly temperature regimes.

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 organisms; third, they visually selected objects moving independently in the water; 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 strong reliance upon living components in the river ecosystem.

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 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 deep 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, 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 entering the drift are produced in upriver areas as well as at each station, and therefore form a food complex presumably originating from different substrate types. 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 (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 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 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 spring spate would increase the quantity of food available to young chinook during the period of their 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 consistant fluctuation within a 24 hr period.

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. It is assumed that feeding corresponded roughly to food organisms occurring free in the water (since benthic forms 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 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 whereas food utilized by larger fish can be very diverse (Mindie, 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 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). Midge 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 greater nutritional value when temperatures were high and more energy was required to maintain growth. (By dry weight, one adult _Hydropsyche cockerelli_ was 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) inundated shoreline areas that were 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 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 Collembola, 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). Permanance 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 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). Theoretically, the combination of rising then decreasing river flow accompanied by rising temperatures are the main environmental factors related with seaward migration. (At any rate, nearly all juvenile chinook leave the free-flowing central Columbia by mid-July.) These factors, occurring annually since recorded history, may well have played an evolutionary role in the development of the spring migration characteristic (Becker, 1970b).

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 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 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 ft^3/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 (inshore areas) 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 warmwater stations was not possible. It is ecologically significant that differences in river temperatures between Priest Rapids and Richland was 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 frenquency 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 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 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 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 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 food for consumption. Comparisons by nonparametric rank correlation coefficient (r') 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 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. Increases in length of juvenile chinook were also 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 feeding of 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 cold and all warmwater stations, when combined and tested by nonlinear least squares power function, revealed no significant differences (Figure 9) and supported a conclusion of proportional allomeric 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 are 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 species dropped rapidly under maximum temperatures of the summer and fall.

Comparison of dry weights of stomach contents of feeding chinook from cold and warmwater stations, on the basis of fish length, differed only slightly when compared by regression analysis (Figure 11). This difference was not considered to be of 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 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 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 drift organisms as food are important ecological features affecting critical thermal evaluation *in situ*.

Addendum

In retrospect, it is evident that precise evaluation of possible thermal effects on food and feeding 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, data thus obtained would not necessarily reflect actual effects in the field because of fish movement and invertebrate drift activity.

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LITERATURE CITED

Alabaster, J. S. 1963. The effects of heated effluents on fish. Intern. J. Air Water Pollution 7:541-563.

Allen, K. R. 1941. Studies on the biology of the early stages of the salmon (*Salmo salar*). II. Feeding Habits. J. Animal Ecol. 10(1): 47-76.

Allen, K. R. 1942. Comparison of bottom faunas as a source of available fish food. Trans. Amer. Fish. Soc. (1943) 71:275-283.

Baldwin, N. S. 1956. Food consumption and growth of brook trout at different temperatures. Trans. Amer. Fish. Soc. 86:323-328.

Bardach, J. E. and R. G. Bjorklund. 1957. The temperature sensitivity of some American freshwater fishes. Amer. Naturalist 91:233-251.

Becker, C. D. 1969. Preliminary report: relationship of thermal discharge to food and feeding of juvenile chinook salmon in the Columbia River at Hanford. U.S. Atomic Energy Comm. Doc. BNWL-1032, Battelle Memorial Institute, Richland, Washington. 27 p. (to be published)

Becker, C. D. 1970a. Feeding bionomics of juvenile chinook salmon in the central Columbia River. Northwest Sci. 44(2): 75-81.

Becker, C. D. 1970b. Temperature, timing and seaward migration of juvenile chinook salmon from the central Columbia River. U.S. Atomic Energy Comm. Doc. BNWL-1472, Battelle Memorial Institute, Richland, Washington. 21 p.

Benson, N. G. 1953. Seasonal fluctuations in the feeding of brook trout in the Pigeon River, Michigan. Trans. Amer. Fish. Soc. (1954) 83:76-83.

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhychus*. J. Fish Res. Bd. Canada 9(6): 265-323.

Brett, J. R. 1956. Some principles in the thermal requirements of fishes. Quant. Biol. 31(2): 75-87.

Brett, J. R. 1965. The swimming energetics of salmon. Sci. Amer. 213(2): 80-85.

Brett, J. R, J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. J. Fish. Res. Bd. Canada 26(6): 2363-2394.

Brett, J. R., and D. A. Higgs. 1970. Effect of temperature on the rate of gastric digestion in fingerling sockeye salmon, Oncorhynchus nerka. J. Fish. Res. Bd. Canada 27(10): 1767-1779.

Breuser, R. 1954. Food and growth of juvenile coho salmon Oncorhynchus kisutch (Walbaum) and chinook salmon Oncorhynchus tshawytscha (Walbaum) in certain Oregon streams. Unpublished MS Thesis, Oregon State University, Corvallis, Oregon.

Burrows, R. E. 1963. Water temperature requirements for maximum productivity of salmon, p. 29-38. In: Water Temperatures--Influences, Effects and Control. Proc. 12th Pacific Northwest Symposium on Water Pollution Research, Corvallis, Oregon.

Bull, H. O. 1936. Studies in conditioned responses in fishes. VII. Temperature perception in teleosts. J. Marine Biol. Assoc. U.K. 21: 1-27.

Clemens, W. A. 1934. The food of young spring salmon in Shuswap Lake, B. C. Canadian Field Natl. 48(9): 142.

Chapman, W. M. and E. Quistorff. 1938. The food of certain fishes of north central Columbia River drainage, in particular, young chinook salmon and steelhead trout. Washington State Dept. Fish., Biol. Rept. No. 37A. 14 p.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Amer. Naturalist 100(913): 345-357.

Chapman, D. W., and R. Demory. 1963. Seasonal changes in the food ingested by aquatic insect larvae and nymphs in two Oregon streams. Ecology 44(1): 140-146.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding, p. 153-176. In: Symposium on Salmon and Trout in Streams (T. G. Northcote, ed), H. R. MacMillan Lectures in Fisheries, Inst. Fisheries, Univ. British Columbia, Vancouver, Canada.

Donaldson, L. R., and F. J. Foster. 1940. Experimental study of the effect of various water temperatures on the growth, food utilization, and mortality rate of fingerling sockeye salmon. Trans. Amer. Fish. Soc. (1941) 70: 339-346.

Edmundson, E., F. E. Everest and D. W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish Res. Bd. Canada 25(7): 1453-1464.

Elliott, J. M. 1967. Invertebrate drift in a Dartmoor stream. Arch. Hydrobiol. 63: 202-237.

Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15(4): 607-624.

Fraser, F. J. 1969. Population density effects on the survival and growth of juvenile coho salmon and steelhead trout in experimental stream channels, p. 253-265. In: Symposium on Salmon and Trout in Streams (T. G. Northcote, ed), H. R. MacMillan Lectures in Fisheries, Inst. Fisheries, Univ. British Columbia, Vancouver, Canada.

Fry, F. E. J. 1964. Animals in aquatic environments: fishes, p. 715-728. In: Handbook of Physiology (C. B. Dill, ed.), Sec. 4., Adaptation to the Environment. Amer. Physiol. Soc. Wash., Washington, D. C.

Fry, F. E. J. 1967. Responses of vertebrate poikilotherms to temperature, p. 375-406. In: Thermobiology (A. V. Rose, ed.), Academic Press, N. Y.

Fulton, L. A. 1968. Spawning areas and abundance of chinook salmon (Oncorhynchus tshawytscha) in the Columbia River basin--past and present. U.S. Fish and Wildlife Service, Spec. Sci. Rept. - Fish. No. 571. 26 p.

Hathaway, E. S. 1927. The relationship of temperature to the quantity of food consumed by fishes. Ecology 8(4): 428-434.

Hartman, G. F. 1958. Mouth size and food size in young rainbow trout, Salmo gairdneri. Copeia 3:233-234.

Hess, A. D. and J. H. Rainwater. 1939. A method for measuring the food preference of trout. Copeia 1939(3): 154-157.

Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. (Transl. from Russian) Yale Univ. Press, New Haven, Conn. 302 p.

Javaid, M. Y. and J. M. Anderson. 1967. Influence of starvation on selected temperature of some salmonids. J. Fish. Res. Bd. Canada 24(7): 1515-1519.

Keenlyside, M. H. and W. S. Hoar. 1954. Effects of temperature on the responses of young salmon to water currents. Behaviour 7(2/3): 77-87.

Latta, W. C. 1969. Some factors affecting survival of young-of-the-year brook trout, Salvelinus fontinalis (Mitchill) in streams, p. 229-240. In: Symposium on Salmon and Trout in Streams (T. G. Northcote, ed), H. R. MacMillan Lectures in Fisheries, Inst. Fisheries, Univ. British Columbia, Vancouver, Canada.

Lindström, T. 1955. On the relation of fish size-food size. Rept. Inst. Freshwater Res. Drottningholm 36:133-147.

Mains, E. M. and J. M. Smith. 1964. The distribution, size, time and current preferences of seaward migrant chinook salmon in the Columbia and Snake Rivers. Fish. Res. Papers, Washington State Dept. Fisheries 2(3): 5-43.

Mihursky, J. A. and V. S. Kennedy. 1967. Water temperature criteria to protect aquatic life., p. 20-32. In: A Symposium On Water Quality Criteria To Protect Aquatic Life (E. L. Cooper, ed.), Spec. Publ. No. 4. Amer. Fish. Soc., Washington, D. C.

Molnár, G. and I. Tölg. 1962. Relation between water temperature and gastric digestion of largemouth bass (Micropterus salmoides Lacépède). J. Fish. Res. Bd. Canada 19(6): 1005-1012.

Moore, A. M. 1968. Water temperatures in the Columbia River Basin July 1966 to September 1967. Open File Report, U.S. Geological Survey, Northwest Water Resources Data Center, Portland, Ore. 39 p.

Mundie, J. R. 1969. Ecological implications of the diet of juvenile coho in streams, p. 135-152. In: Symposium on Salmon and Trout in Streams (T. G. Northcote, ed.), H. R. MacMillan Lectures in Fisheries, Inst. Fisheries, Univ. British Columbia, Vancouver, Canada.

Nakatani, R. E. 1969. Effects of heated discharges on anadromous fishes, p. 294-317. In: Biological Aspects of Thermal Pollution (P. A. Krenkel and F. L. Parker, eds.), Vandebuilt Univ. Press, Nashville, Tenn.

Reimers, N. 1957. Some aspects of the relation between stream foods and trout survival. Calif. Fish Game 43:43-69.

Rodgers, D. E. 1968. A comparison of the food of sockeye salmon fry and threespine sticklebacks in the Wood River lakes, p. 1-43. In: Further Studies of Alaska Sockeye Salmon (R. L. Burgner, ed.), Univ. Washington, Publ. in Fisheries, New Series, Vol. III. Seattle, Wash.

Rutter, C. 1904. Natural history of the quinnat salmon, a report on investigations in the Sacramento River, 1896-1901. Bull. U.S. Fish Comm. for 1902. 22:65-141.

Waters, T. F. 1969. Invertebrate drift - ecology and significance to stream fishes, p. 121-134. In: Symposium on Salmon and Trout in Streams, (T. G. Northcote, ed.), H. R. MacMillan Lectures in Fisheries, Inst. Fisheries, Univ. British Columbia, Vancouver, Canada.

Watson, D. G. 1970. Fall chinook salmon spawning in the Columbia River near Hanford. 1947-1969. U.S. Atomic Energy Commission Doc. BNWL-1515, Battelle Memorial Institute, Richland, Washington, 40 p.

Whittaker, R. H. and C. W. Fairbanks. 1959. A study of plankton copepod communities in the Columbia Basin, southeastern Washington. Ecology 39(1): 46-65.

Windell, J. T. 1967. Rates of digestion in fishes, p. 151-173. In: The Biological Basis of Freshwater Fish Production (S. D. Gerking, ed.), Blackwell Sci. Publ., Edinburg, England.

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