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Title: EFFECTS OF TEMPERATURE AND RATION SIZE ON THE GROWTH OF JUVENILE CHUM SALMON, *Oncorhynchus keta*, IN SEA WATER

Abstract approved by: Redacted for privacy
(Gerald E. Davis)

The effects of temperature and ration on growth, food consumption, and food conversion efficiency of chum salmon, *Oncorhynchus keta*, in sea water were studied in two experiments conducted during the spring, summer, and fall, 1973, at the Oregon State University Marine Science Center, Newport, Oregon. The test temperatures employed in the study were nominally 11.0, 13.5, 16.5, and 20.0 C. The fish were fed the Oregon Moist pellet. Rations fed during the first experiment (May 29-July 7) were 3, 6, 9, and 15 percent of the dry body weight of the fish per day. Rations fed during the second experiment (Sept. 28-Nov. 7) were 3, 8, 13, and 18%/day.

The growth rates of the fish increased with an increase in ration level at all test temperatures. Growth during the first experiment was markedly lower than during the second experiment at each ration level.

Growth rates during both experiments were generally higher at 13.5 C than at lower or higher temperatures. During the first experiment, growth rates at the highest test temperatures (16.5 and 20.0 C) were positive only at the highest ration level (15%/day). Values of growth rate during the second experiment were positive at all but the lowest level (3%/day) at all test temperatures.

Food conversion efficiency was found to be directly related to ration level and inversely related to temperature. At low consumption rates, increases in temperature markedly reduced efficiency. As ration levels increased, the effects of temperature were ameliorated. The highest conversion efficiencies at the lowest temperatures reflect the decrease in maintenance rations with a decrease in temperature. As with growth, the highest conversion efficiencies were generally found at 13.5 C.

Maximum food consumption rates and maintenance rations were generally lower in experiment II than in experiment I. These differences in consumption and maintenance may be attributable to the larger sizes of fish used in the second experiment than in the first experiment.

The number of deaths resulting from Vibrio disease during experiment I was found to be directly related to temperature and inversely related to ration level. Mortality resulting from Vibrio disease during experiment II was generally highest at the highest temperatures. Unlike experiment I, there was no clear relationship between mortality and ration level during the second experiment.

The results of the study suggest that elevation of sea water temperatures beyond approximately 13.5 C does not benefit the growth of chum salmon, but the extent to which disease may have influenced the growth and food relationships of the fish at elevated temperatures could not be adequately evaluated. Further studies to determine the temperatures most favorable for the culture of chum salmon should be undertaken upon development of methods for the control of _Vibrio_ disease.

Effects of Temperature and Ration Size on the Growth of Juvenile Chum Salmon, *Oncorhynchus keta*, in Sea Water

by

Gerald Duane Rowan

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I. INTRODUCTION

The electric utility industry is growing rapidly as evidenced by the increasing number of steam electric generating stations. Where once-through cooling is employed, a one million kilowatt plant is capable of producing 700,000 gallons of heated water per minute (McNeil, 1970; North et. al., 1969).

It has been proposed that heated sea water from the condensers of a steam electric station can enhance the growth of fish and shellfish and provide high yields of animal protein from small areas (ponds or raceways) where the environment is controlled (Gaucher, 1970). The possibilities of using heated discharge water to extend the growing season has also stimulated an interest in industrial culturing of fish and shellfish. Potential production of fish and shellfish in thermally enriched waters from United States power stations in 1965 is estimated to be between 0.62 and 1.25 billion pounds per year, which represents between 25 and 50% of the United States fish landings (Gaucher, 1970).

Experiments are now underway at thermal power stations on the culture of carp, *Tilapia*, sole, plaice, and oysters to determine the feasibilities of rearing these animals in heated discharge water from steam electric stations (Gaucher, 1970; Shelbourne, 1970; Nash, 1969). Our knowledge is less adequate for determining the possibilities of rearing salmon and trout in heated sea water.

The fact that many species of salmon and trout adapt readily to sea water as fry affords us the advantage that freshwater would not be required beyond the larval stages. Sato and Kashwagii (1969) studied the differences in growth of chum salmon, *Oncorhynchus keta*, reared in sea water and in freshwater. They found that fish reared in sea water grew to a larger size than fish reared in freshwater. These findings agree with the results of Canagaratnam (1959) who found that the growth of chum salmon was greater at $30^{o}/oo$ than at $6^{o}/oo$, and that the growth of sockeye salmon, *O. nerka*, at a salinity of $6^{o}/oo$, and the growth of coho salmon, *O. kisutch*, at 12 and $18^{o}/oo$, was greater than at a salinity of $0^{o}/oo$.

Information on the temperature requirements of salmon and trout has been based mainly upon the relationships between metabolic rate and temperature and studies of lethal temperatures (Brett, 1952, 1971; Fry, 1947). Many people have studied the effects of temperature on growth using either maintenance or ad libitum ration (Brown, 1946; Baldwin, 1957; Banks et. al., 1971; Donaldson and Foster, 1940). However, Warren and Davis (1967) emphasized the importance of feeding a range of ration levels at different temperatures to determine the effects of an environmental factor on the growth of an animal.

Brett et. al. (1969) conducted an extensive study on sockeye salmon, using five rations and six temperatures. He concluded that temperatures from 5 to 17 C are most favorable for growth and food conversion of young sockeye, and that a physiological optimum occurs around 15 C. Everson (1973) showed that growth rates of juvenile coho salmon kept at control temperatures were generally higher than those of fish exposed to elevated temperatures. Wurtsbaugh (1973) studied the effects of temperature, ration size, and fish size on the growth of juvenile steelhead trout, Salmo gairdneri. He found decelerating curvilinear relationships between rates of food consumption and growth in most experiments. As feeding levels increased, the effects of elevated temperature were ameliorated. Averett (1969), studying juvenile coho salmon, observed an increase in consumption rate with each incremental change in temperature from 5 to 17 C.

This paper reports on the combined effects of temperature and ration on growth, food consumption, and food conversion of chum salmon in sea water. Two temperature x ration experiments, utilizing four temperatures and four rations, were conducted during the spring, summer, and fall, 1973, at the Oregon State University Marine Science Center, Newport, Oregon. The objectives were to determine the temperatures and ration levels most favorable for growth and food conversion efficiency of chum salmon in sea water.

II. METHODS AND MATERIALS

Source and Culturing of Fish

The chum salmon used in the study were from the 1972 year class and were obtained from the Oregon State University experimental salmon hatchery on Whiskey Creek, a tributary to Netarts Bay, Oregon. In earlier work with sea water salmon culture (Robert Malouf, personal communication), problems were encountered with bacterial kidney disease, caused by freshwater bacteria. The disease is chronic, but can cause high mortalities at elevated temperatures. It was hypothesized that since the disease is of freshwater origin, it could be avoided by keeping the fish in a disease-free environment during their short freshwater period. Accordingly, the following sterilization procedures were employed: 1) sterilization of the gravel incubators with chlorine before use; 2) sterilization of the eggs with a bath of Wescodyne (an iodine based detergent, West Chemical Products, Inc., Long Island City, New York); and 3) continuous sterilization of the water supply (de-chlorinated city water) with ultra-violet light.

After the fish absorbed their yolk sacs, they were transported to two large sea water rearing tanks at the Oregon State University Marine Science Center. Vibriosis, caused primarily by the marine bacterium *Vibrio anquilarum*, is also known to be a serious problem in sea water salmon culture. In an attempt to minimize expected difficulties from *Vibrio* disease, a vaccination program was carried out. This procedure consisted of feeding the fish killed bacterial cells mixed with starter mash (Oregon Moist pellet, Bio-Products, Warrenton, Oregon) at a concentration of 10 mg/g of food (John Fryer, personal communication). The fish were fed for a period of 15 days at the rate of 1.5% of their wet weight per day. At the end of 15 days, the fish were fed a standard diet of Oregon Moist pellet.

Experimental Apparatus

The 16 oval tanks (approximately 380 liters) used in the experiments were constructed of plywood and coated on the insides with fiberglass (Figures 1, 2; see Alderdice et. al., 1966). Each was equipped with a double standed central drain pipe to provide adequate circulation and self cleaning. Recirculating pumps in each tank provided constant water velocities and even temperature distributions. Air stones were employed in each tank to insure high levels of oxygen. Oxygen concentrations never fell below 7.2 mg/l in experiment I, and 6.0 mg/l in experiment II (Appendix I). Plastic screens were placed over each tank to reduce fish activity and keep fish from escaping.

Sea water used in the experiments was pumped from Yaquina Bay. The water was first passed through a sand filter (Figure 3), and

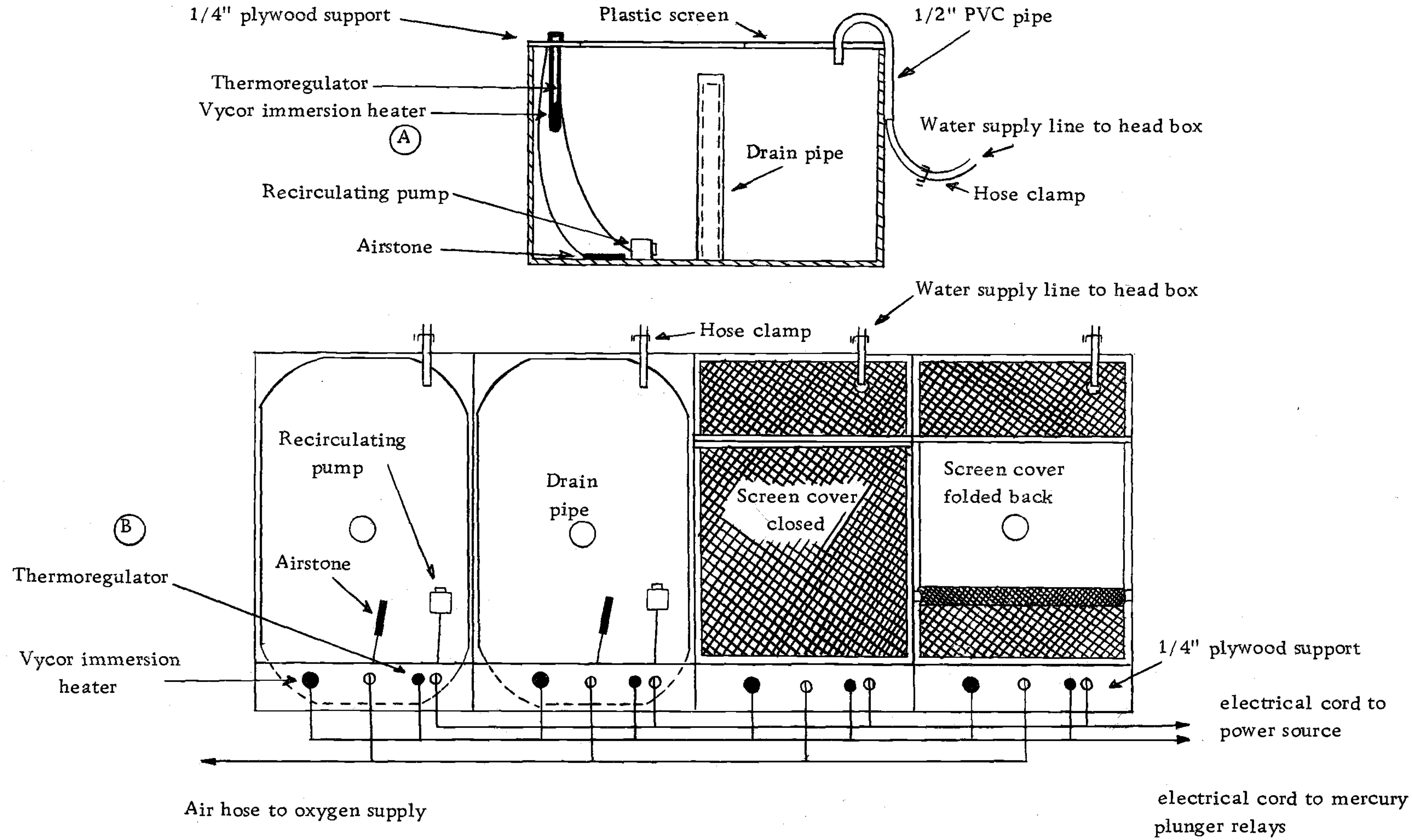

Figure 1. A: Side view of experimental tank used in the growth experiments.

B: Top view of experimental tanks (one of four units).

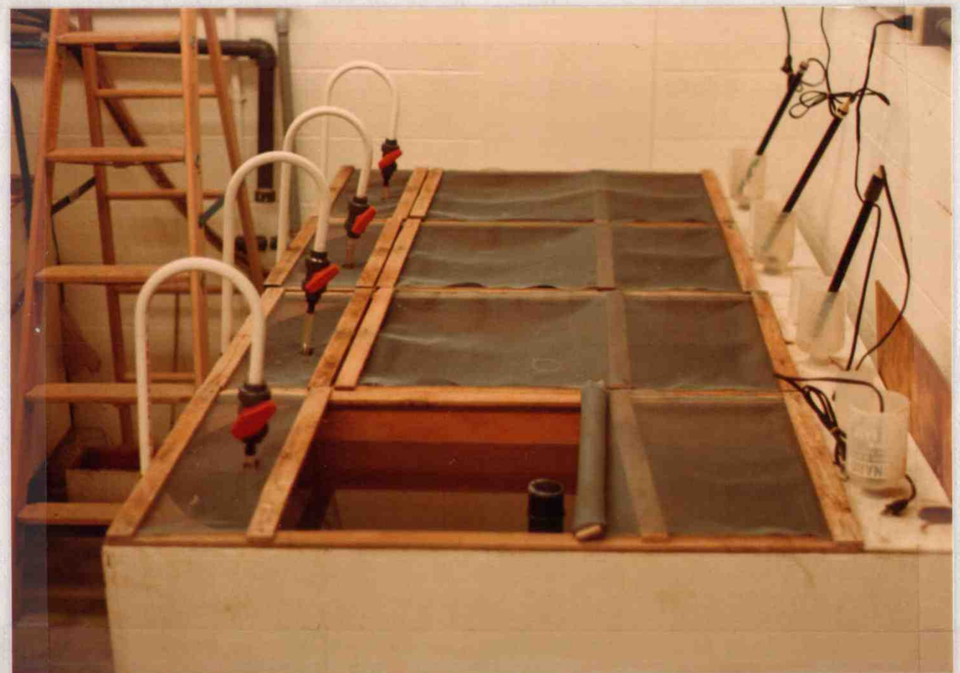

Figure 2. View of experimental tanks used in the growth experiments (one of four units).

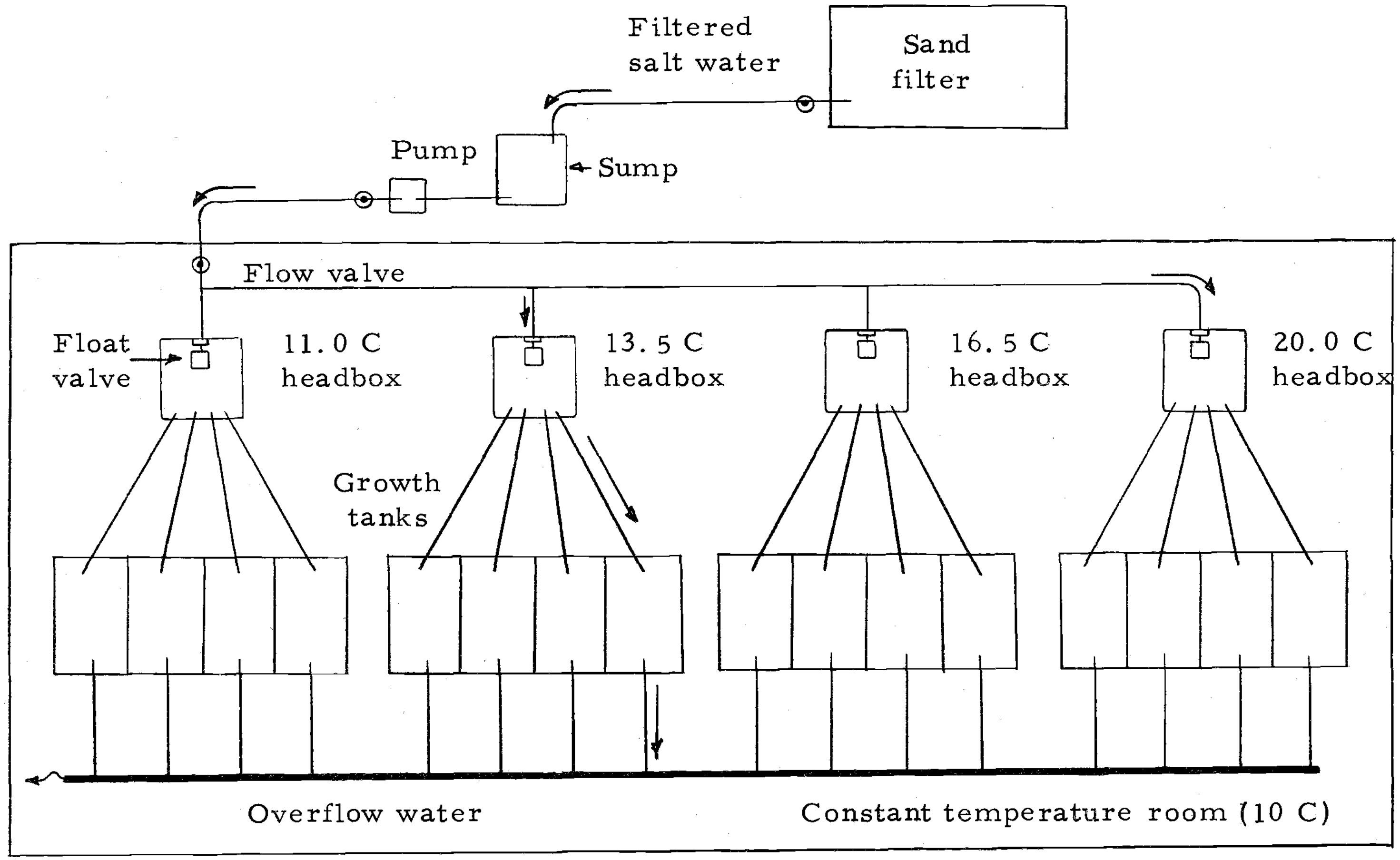

Figure 3. Schematic diagram of water supply system.

then pumped through PVC pipe into headboxes in the laboratory. One headbox was provided for each of the test temperatures. The headboxes were constructed of plywood and fiberglass, and had a capacity of approximately 340 liters. The water flows into the headboxes were regulated by float valves. Four lines (Tygon tubing, 1.27 cm inside diameter) extended from each headbox to supply water by gravity flow to each tank.

The test temperatures employed in the study were nominally 11.0, 13.5, 16.5, and 20.0 C. Water at the three elevated temperatures was heated with thermostatically controlled 1,000 and 1,500-watt Vycor immersion heaters. The 11.0 and 13.5 C temperature treatments did not remain constant in experiment I (May 29-July 7) because of diurnal and seasonal temperature fluctuations in the water supply. Temperatures reached 15.8 C toward the latter part of the experiment (Appendix I). A modification was therefore made in experiment II (Sept. 28-Nov. 7). Water which supplied the tanks at 11 C was first passed through a heat exchanger. The heat exchanger consisted of approximately 2,200 cm of glass tubing (0.79 cm inside diameter) which was exposed to the air in a cold room kept at a constant temperature of approximately 4 C. This modification kept temperatures from rising above 12.4 C and the average temperature for the four tanks kept nominally at 11.0 C was 10.6 C (Appendix I).

Water flows were standardized depending upon the numbers and sizes of fish, and water temperatures in each tank. Flows were calculated from a table provided by Piper (1971, p. 4), and multiplied by 150% to insure an adequate supply of oxygen. The water flows were regulated by screw compressor hose clamps attached to the Tygon tubing, and were measured by timing the flows into a 1,000 ml graduated cylinder.

Dissolved oxygen concentrations were determined twice each week during experiment I with an oxygen meter that was temperature compensated and sensitive to 0.05 ppm. The meter was calibrated by comparing readings with values obtained periodically by use of the Winkler method (American Public Health Association, 1965). The meter was inoperative during experiment II, and oxygen levels were measured once each week by the Winkler method.

Values of pH were measured at 10 day intervals in experiment II. The pH values were similar in all the tanks and they ranged from 7.70 to 8.04 during the experiment. No values of pH were recorded in the first experiment. However, it would be expected that pH levels during the first experiment also remained relatively constant, considering the high buffering capacity of sea water.

The salinity of the sea water was measured three times each week by use of a hydrometer, and it remained relatively unchanged throughout the experiments. The salinities averages 32.8 and 33.2‰ in experiments I and II, respectively.

The experiments were conducted in a constant temperature room at 10 C to avoid the modifying effects of changing air temperature on the test temperatures. Fluorescent lamps were used to illuminate the tanks and were controlled by a time switch set to operate between the hours of 0800 and 1700 (PST).

Experimental Procedure

At the beginning of experiment I, 120 fish were randomly drawn from the pooled group of fish and placed in each tank. The average initial wet weight of the fish used in this experiment was 1.17 ± 0.4 g (Appendix II). The fish available for use in experiment II were larger and more variable in size than those used in experiment I. Since there was an insufficient number of fish of uniform size available for use in experiment II, the fish were graded into three size groups, and equal numbers were randomly drawn from each size group for stocking in the tanks. Each tank was stocked with 94 fish. The average initial wet weight of the fish used in this experiment was 12.44 ± 3.10 g (Appendix II). The fish were kept at the control temperature for one day; then the temperatures were increased 1 C per day until the desired temperatures were reached. The fish were then kept at the test temperatures for two days before the beginning of the experiments. Water temperatures were measured twice each day in experiment I and once each day in experiment II with ASTM partial immersion thermometers accurate to 0.5 C.

The fish were fed the Oregon Moist pellet. Rations were calculated as percentages of the dry body weight of the fish per day. Rations fed in the first experiment were 3, 6, 9, and 15%/day, and the fish were fed on the 'fair share' plan of Brett et al. (1969). The 3% daily ration was therefore presented as 3% once each day, and 15% as 3% five times each day. Rations fed during the second experiment were 3, 8, 13, and 18%/day. The 8% daily ration was presented as 4% twice each day, 13% as 4.3% three times each day, and 18% as 6% three times each day. At each feeding, the fish were offered as much of the prescribed individual ration level as they would consume, and any remaining food was weighed to provide a measure of the actual daily food intake.

To provide a measure of growth in both experiments, a sample of fish was periodically drawn from each tank. Twenty fish were removed every 10 days in experiment I, and every 14 days in experiment II. The fish were crowded into one end of the tank and a small dip net was drawn vertically through the group. The fish were killed by placing them in 150 ppm M. S. 222 (tricaine methanesulfonate, Sigma Chemical Co.), and then rolled on a damp cloth to remove excess surface moisture. The fish were weighed to the nearest

0.01 g with a Mettler toploading balance and fork lengths were taken to the nearest 0.1 cm (Appendix II). The fish were then dried in an oven at 100 to 105 C for 24 hours, and dry weight determinations were made to the nearest 0.01 g (Appendix II). The fish were not fed 24 hours prior to sampling days. Feeding levels and water flows were adjusted following each sampling.

Dead fish were removed daily from each tank. Most of the deaths were believed to have resulted from Vibriosis, and a small sample (10 fish or less) was analyzed approximately every week by Mr. Dave Ransom, graduate student in Microbiology, to confirm the cause of deaths. All the fish that were analyzed showed the presence of *Vibrio* disease.

Calculations

Values of growth and food consumption rate were expressed as average relative growth and average relative food consumption rates, respectively. These were calculated as follows:

$$\text{Growth rate} = \frac{W_2 - W_1}{0.5\,(W_1 + W_2)t}$$

$$\text{Consumption rate} = \frac{C}{0.5\,(W_1 + W_2)t}$$

where:

W_1 = initial average dry weight of the sample of fish

W_2 = final average dry weight of the sample of fish

t = length of sampling interval in days

C = dry weight of food consumed

Growth and consumption rates were then multiplied by 100 and expressed as a percentage of the dry body weight of the fish per day.

Food conversion efficiencies were calculated as follows:

$$\text{Food conversion efficiency} = \frac{G}{I}$$

where:

G = average change in dry weight of fish

I = average food consumption of fish in dry weight

Efficiency values were multiplied by 100 and expressed as percentages.

III. RESULTS AND INTERPRETATION

The fish experienced high mortality rates in many of the temperature x ration treatments before the experiments were concluded. For this reason, the mean values of growth rate, food consumption rate, and food conversion efficiency were based mainly on data obtained by sampling fish during the first three 10-day sampling periods in experiment I, and during the first two 14-day sampling periods in experiment II (Appendix III).

Experiment I

The relationship between rate of food consumption and growth was one of increased growth rate with increased ration at each temperature (Table 1; Figure 4). Although the highest growth rate was observed in the group receiving the greatest ration at 11 C, growth rates at the remaining ration levels were higher at 13.5 C. Differences between growth rates at 11.0 C and 13.5 C were not great at any ration level, possibly due to the small difference in actual mean temperatures to which the fish were exposed, 12.0 and 13.4 C, respectively (Figure 6). Growth rates were lowest at 20.0 C.

Figure 4 also shows quite clearly the increased metabolic costs to the fish of increased temperature. At 20 C, a ration of approximately 14.5%/day was required just to maintain the fish, that

Table 1. Average relative rates of growth and food consumption, and food conversion efficiencies of chum salmon kept at different ration levels and temperatures during experiments I and II. The numbers in parenthesis indicate sample sizes when fewer than 20 fish were available during the third 10-day sampling period in experiment I, and during the second 14-day sampling period in experiment II.

Experiment I					Experiment II				
Mean Temperature (C)	Nominal Ration (%/day)	Growth Rate (%/day)	Consumption Rate (%/day)	Conversion Efficiency (%)	Mean Temperature (C)	Nominal Ration (%/day)	Growth Rate (%/day)	Consumption Rate (%/day)	Conversion Efficiency (%)
11.9	3	-0.95	3.12	-21.99	10.2	3	0.38	3.01	14.81
12.3	6	-0.67	5.96	- 9.89	10.4	8	1.48	7.92	21.78
12.2	9	0.42	8.97	4.82	10.9	13	1.84	11.91	18.58
11.7	15	1.98	15.07	14.95	10.8	18	1.69	13.51	14.75
13.9	3	-0.79	3.18	-19.16	13.3	3	-0.16	2.91	- 4.56
13.8	6	-0.30	6.00	- 4.87	13.2	8	1.80	7.87	28.39
13.7	9	1.14	9.24	13.16	12.8	13	2.76	12.75	28.42
13.5	15	1.78	14.82	13.69	13.9	18	2.86 (15)	14.91	27.91
16.5	3	-1.75 (5)	3.18	-48.05	16.5	3	0.15 (16)	3.04	8.44
16.6	6	-0.72	6.16	-10.47	16.5	8	1.08	7.97	15.26
16.6	9	-0.13	9.28	- 1.18	16.0	13	2.48 (13)	13.09	22.72
16.7	15	1.13	14.96	9.91	16.2	18			
19.6	3				19.4	3	-0.60 (9)	3.00	-20.05
19.8	6				19.8	8			
19.6	9	-0.76 (11)	10.30	- 6.25	18.8	13			
19.4	15	0.13	15.04	1.42	19.9	18	1.69	15.85	12.56

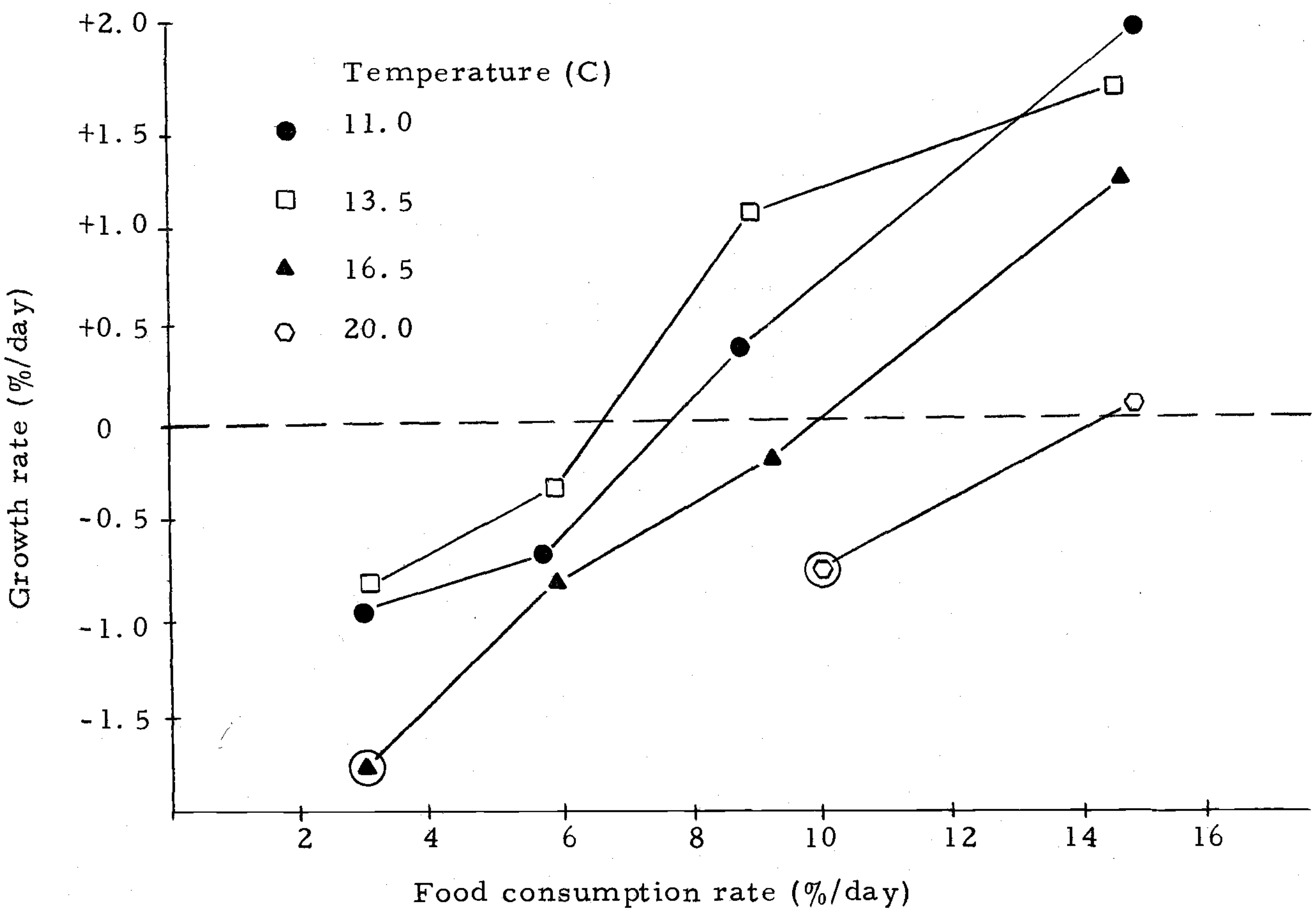

Figure 4. Relationships between rates of food consumption and growth of chum salmon kept at different temperatures during experiment I. Circled points are based upon a sample of fewer than 20 fish during the third 10-day sampling period.

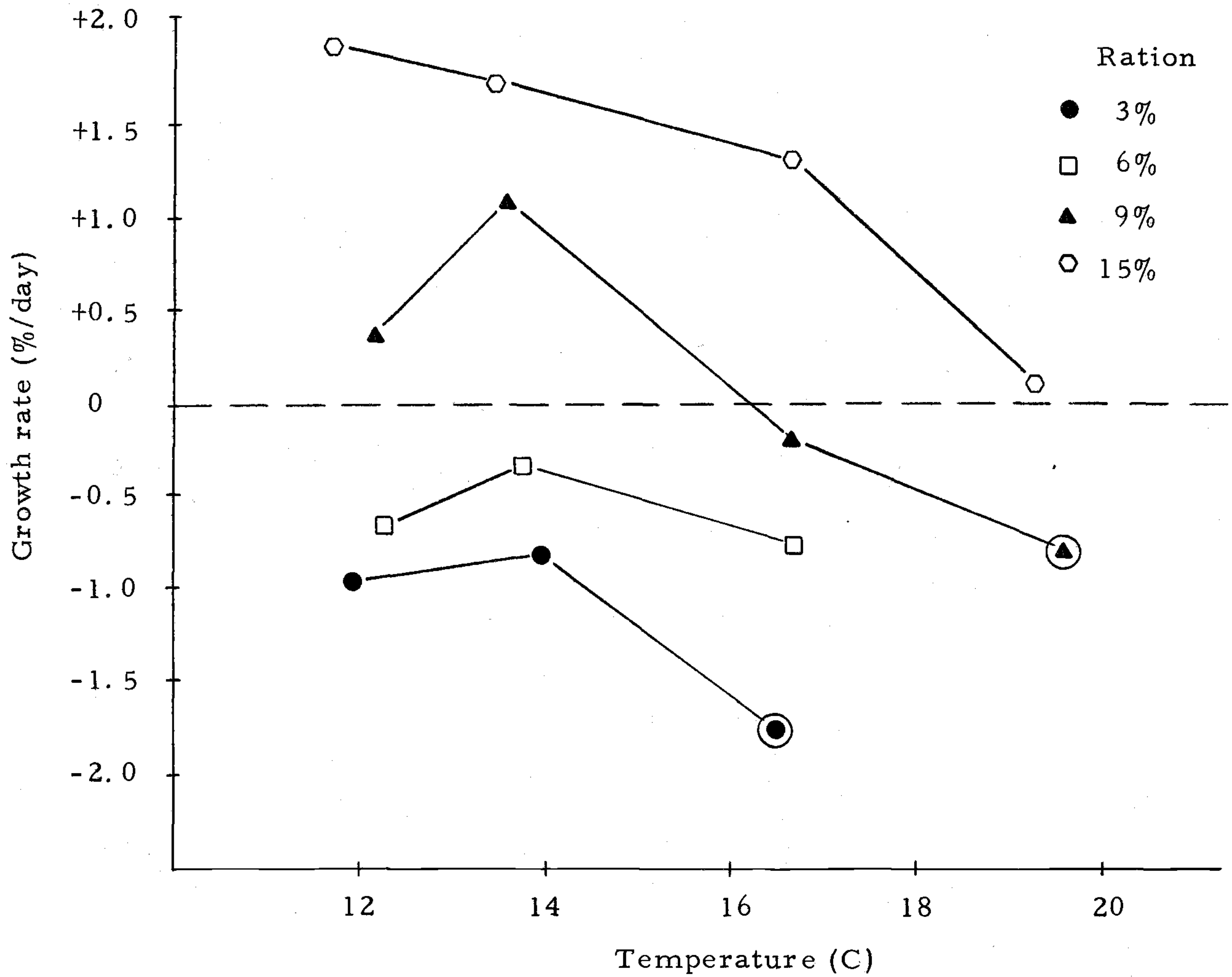

Figure 5. Relationships between temperature and rate of growth of chum salmon fed at four ration levels during experiment I. Circled points are based upon a sample of fewer than 20 fish during the third 10-day sampling period.

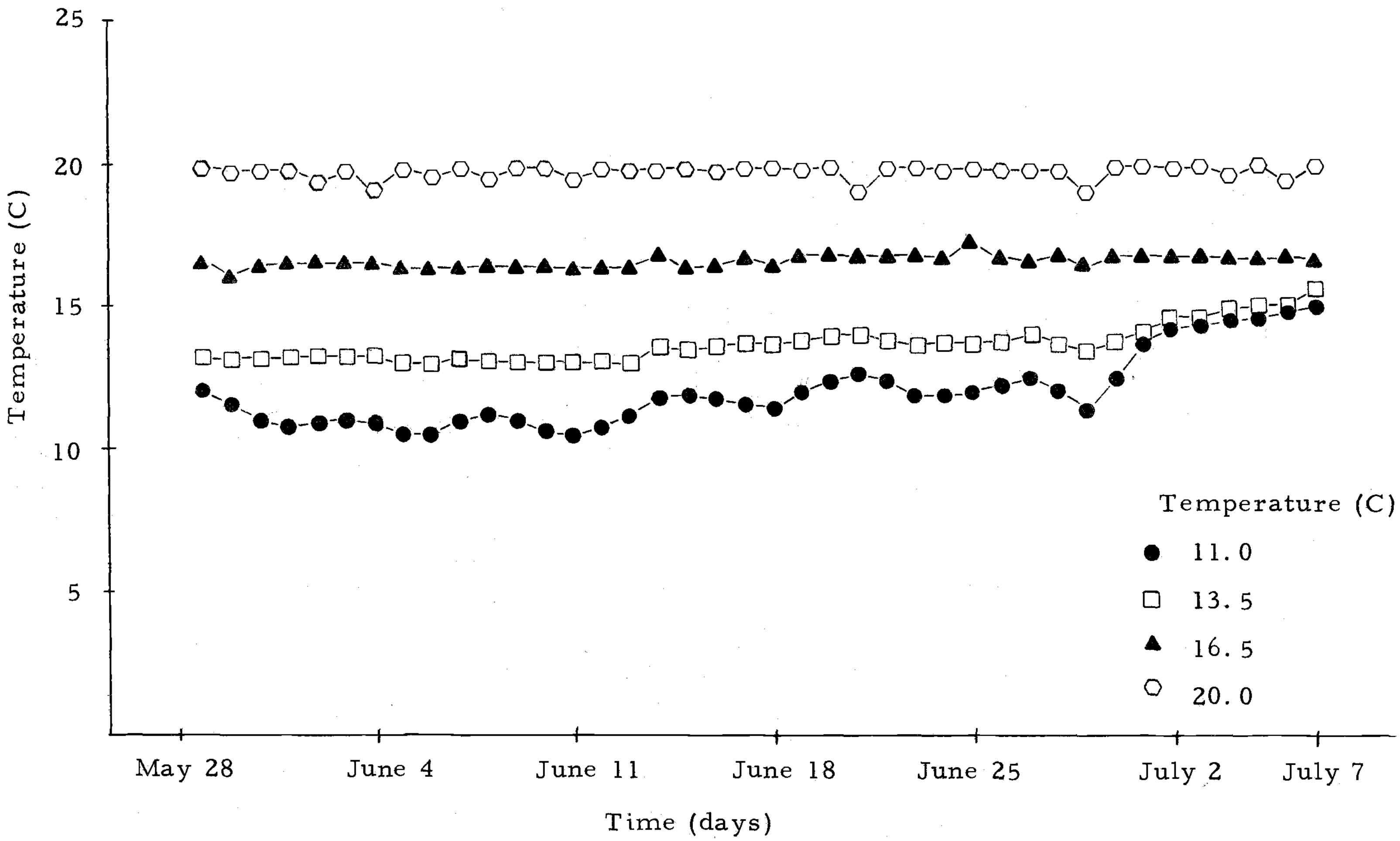

Figure 6. Mean daily temperatures to which chum salmon were exposed during experiment I. The temperatures are averages of four tanks kept at each test temperature.

is, to prevent either gain or loss of weight. With a decrease of temperature, the maintenance ration also decreased. The maintenance ration at 16.5 C was approximately 10%/day, and at the two lowest temperatures, it ranged from 6 to 7%/day. The maintenance ration at 13.5 C was slightly lower than at 11 C, although the difference was small.

Food conversion efficiency was found to be directly related to ration level (Figure 7), and inversely related to temperature (Figure 8). Efficiency values were generally negative at lower ration levels and positive at the higher levels. Values of efficiency increased rapidly with increases in ration from 3 to 9%/day, but then began to level off at levels from 9 to 15%/day. At low consumption rates, increases in temperature markedly reduced conversion efficiency. As ration levels increased, the effects of temperature were not as pronounced. The fish apparently were able to grow more efficiently over a wider range of temperatures at high ration levels than at low ration levels. As with growth, the best food conversion efficiencies were found at the two highest rations (9 and 15%/day) at 13.5 C, and at the highest ration (15%/day) at 11 C. Conversion efficiencies were lowest at 20.0 and 16.5 C.

The number of deaths resulting from Vibrio disease was found to be directly related to temperature and inversely related to ration (Figure 9). The numbers that died increased by 28.3% from 11.0 to

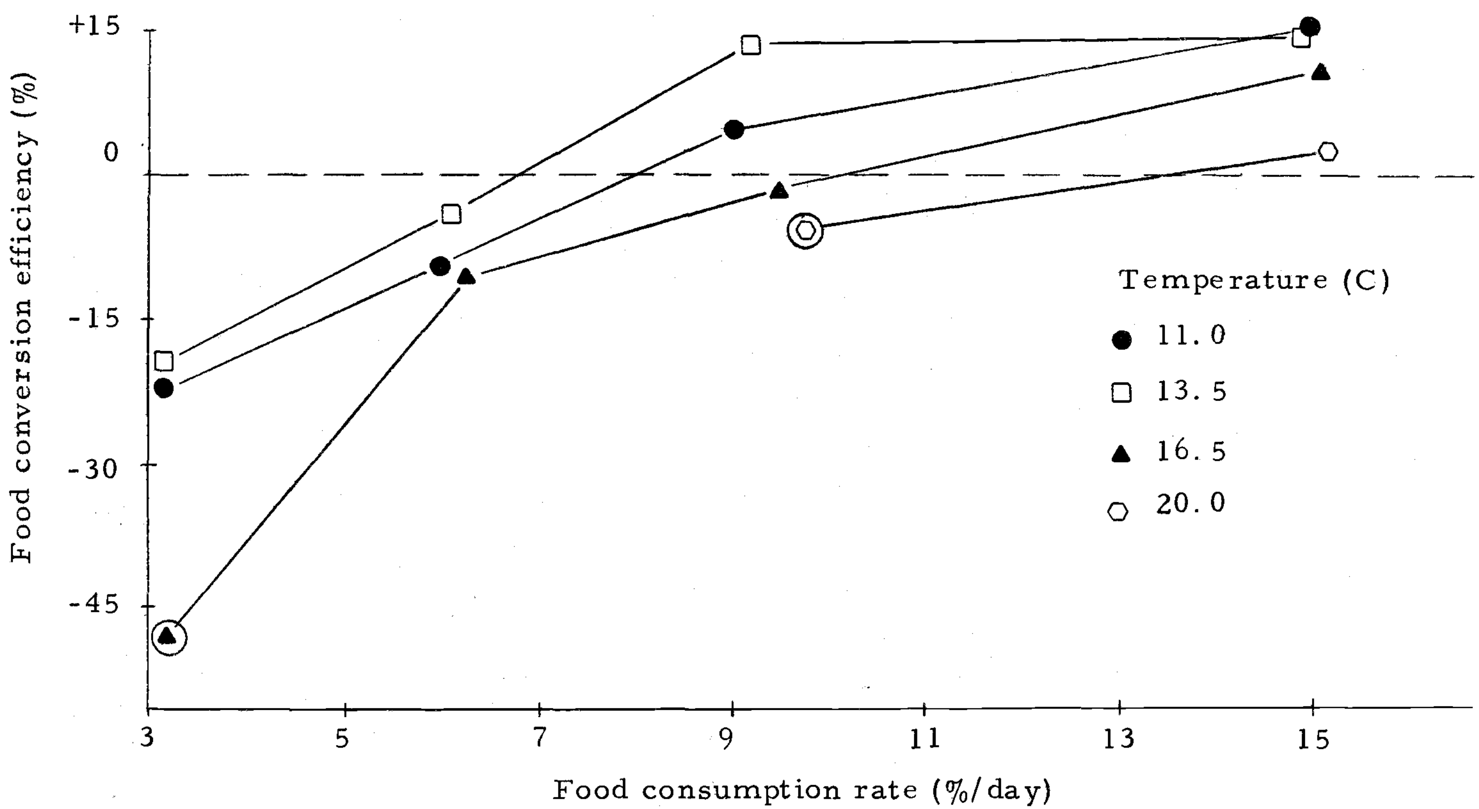

Figure 7. Relationships between food consumption rate and food conversion efficiency of chum salmon kept at different temperatures during experiment I. Circled points are based upon a sample of fewer than 20 fish during the third 10-day sampling period.

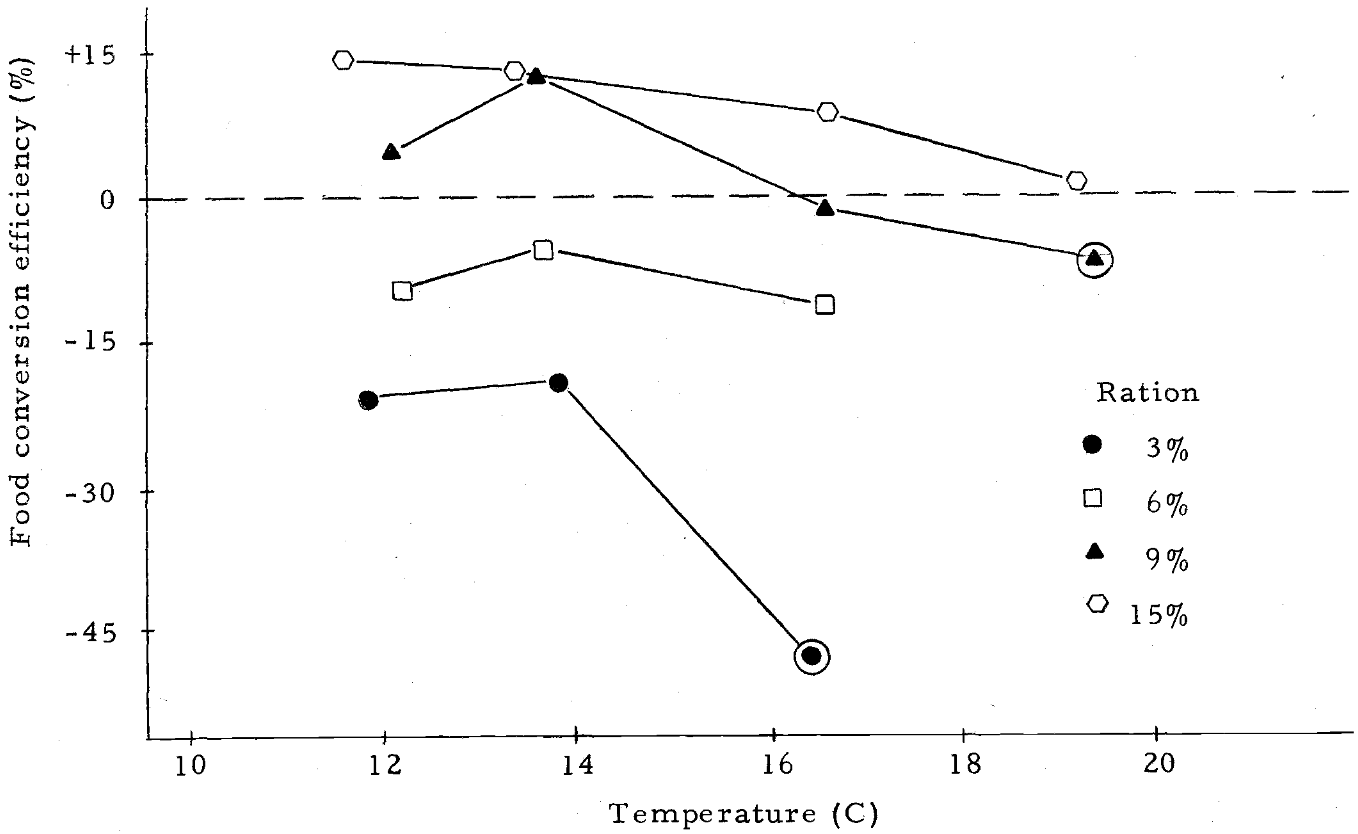

Figure 8. Relationships between temperature and food conversion efficiency of chum salmon fed at four ration levels during experiment I. Circled points are based upon a sample of fewer than 20 fish during the third 10-day sampling period.

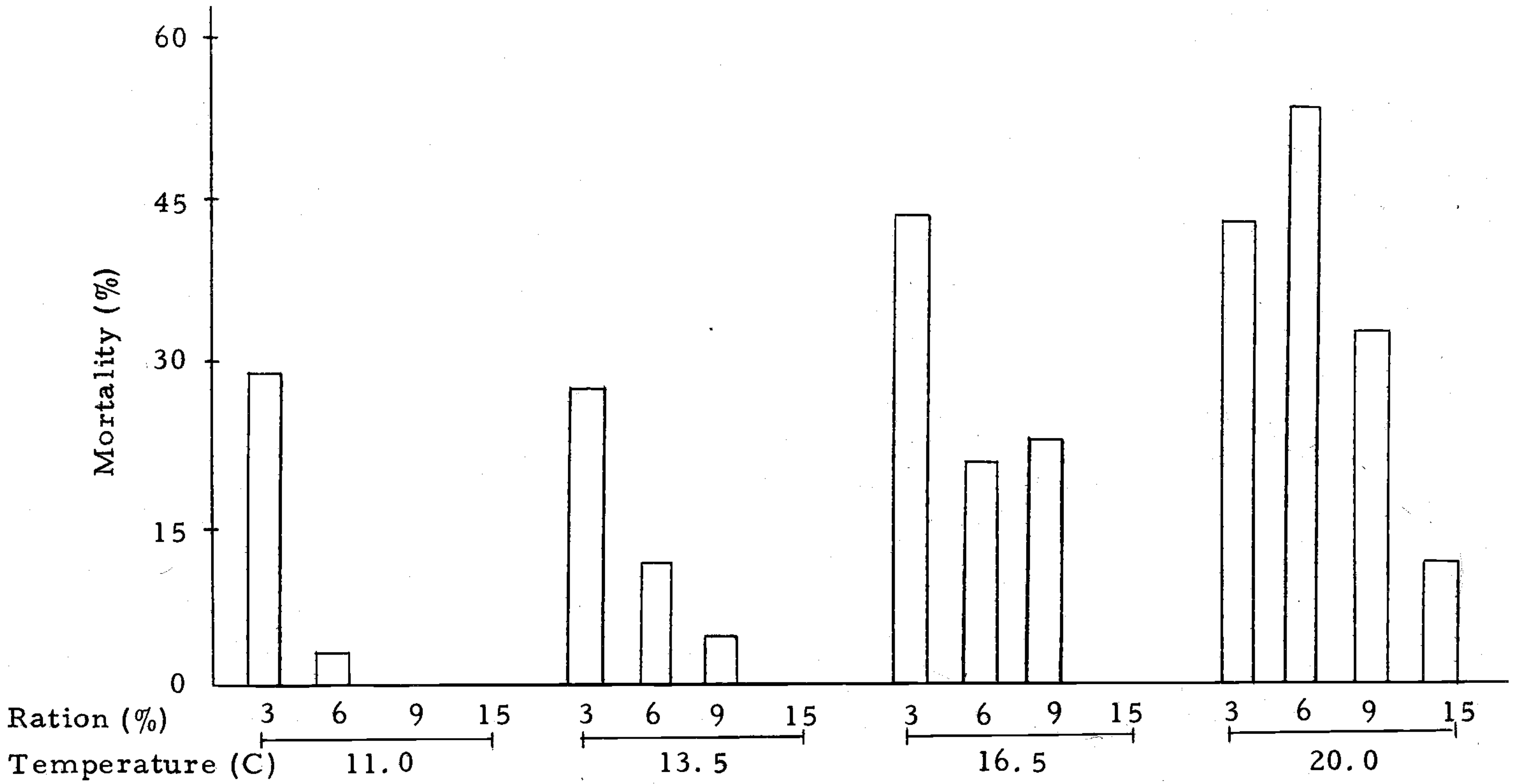

Figure 9. Mortality rates of chum salmon, kept at different temperatures and ration levels during experiment I, which were attributed to Vibrio disease.

13.5 C, 63.5% from 11.0 to 16.5 C, and 77.1% from 11 to 20 C. At the two lowest temperatures (11.0 and 13.5 C) and the two lowest rations (3 and 6%/day), only six fish died resulting from Vibrio disease. At the two highest temperatures (16.5 and 20.0 C) and two lowest rations, 78 fish died (Appendix IV). The results suggest that insufficient food and high temperature interact importantly in influencing the number of deaths caused by Vibrio disease.

Experiment II

The results in experiment II were similar in most respects to those of the first experiment. Relationships established between rates of food consumption and growth (Figure 10) at the different test temperatures (Figure 11) show that the effects of temperature on fish growth were dependent upon consumption rates.

In experiment II, however, it was found that maximum food consumption by the fish was somewhat less than in experiment I. Even though the nominal ration offered at the highest feeding level was 18%/day, consumption rates of fish kept at 11.0, 13.5, 16.5, and 20.0 C were only 13.51, 14.91, 13.09, and 15.85%/day, respectively (Table 1). It was found that the maintenance ration was also less in experiment II than in experiment I at all temperatures. At 20 C, the maintenance ration was approximately 6%/day. At the three lower temperatures, maintenance rations ranged from approximately 1 to

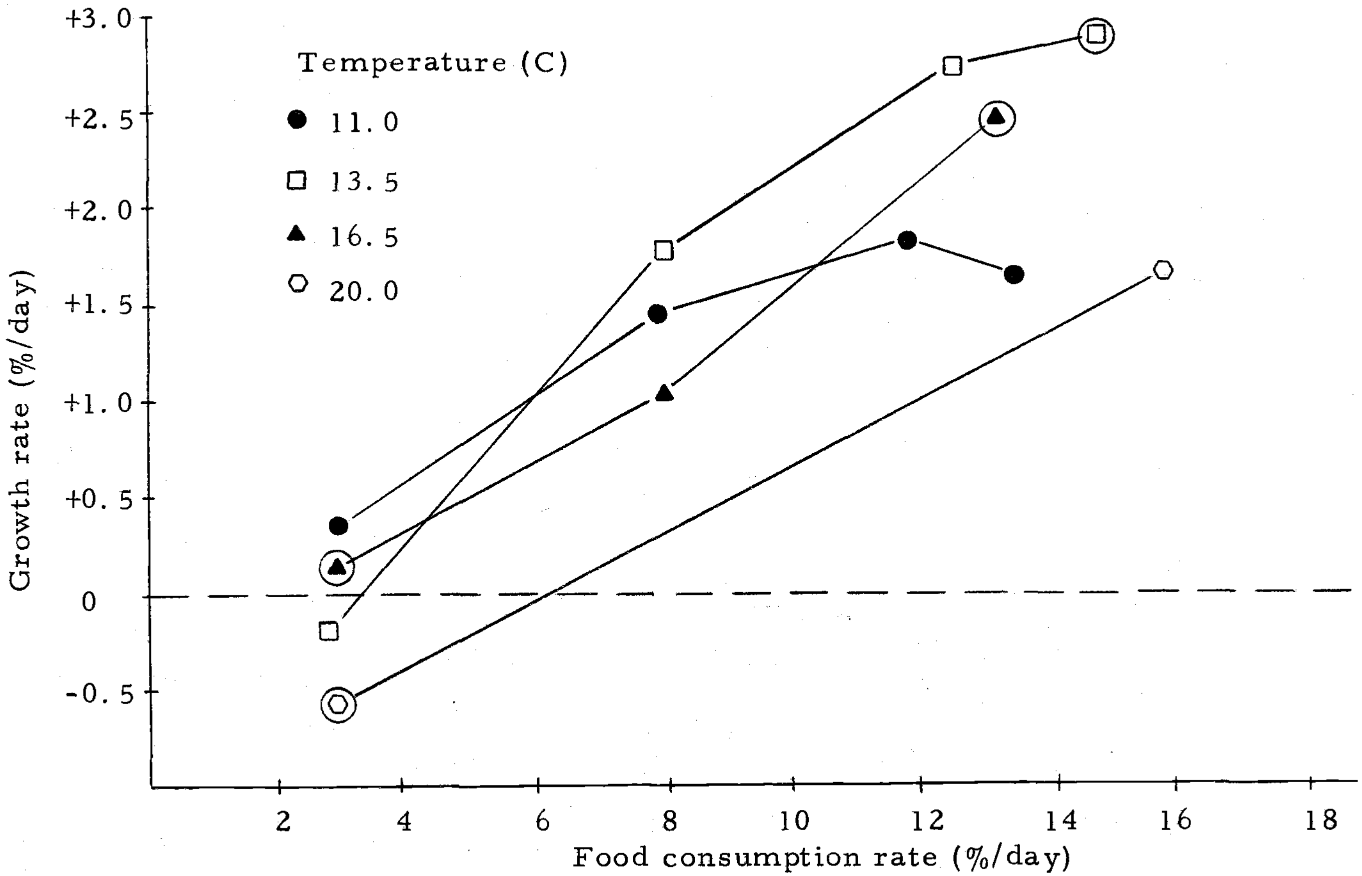

Figure 10. Relationships between rates of food consumption and growth of chum salmon kept at different temperatures during experiment II. Circled points are based upon a sample of fewer than 20 fish during the second 14-day sampling period.

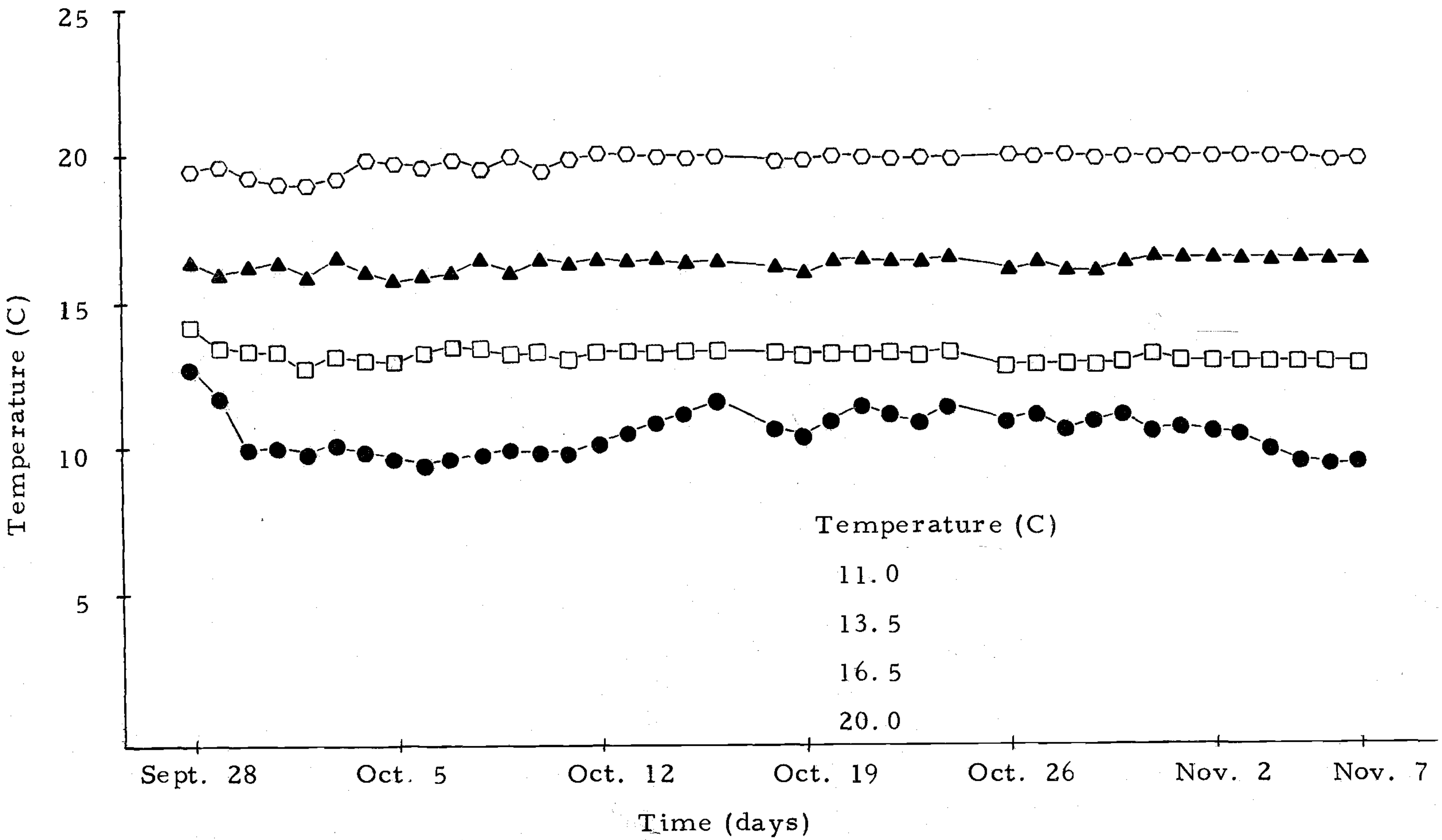

Figure 11. Mean daily temperatures to which chum salmon were exposed during experiment II. The temperatures are averages of four tanks kept at each test temperature.

3%/day. These differences in consumption and maintenance may be attributable to the larger sizes of fish used in the second experiment than in the first experiment. It is generally true that fish consume and require a lower fraction of their body weight in food as they become larger (Brown, 1946; Paloheimo and Dickie, 1965; Wurtsbaugh, 1973).

The highest growth rates were generally recorded at the highest ration levels at any given temperature (Figure 10). One exception was observed at 11 C where the highest growth rate was recorded at the nominal ration level of 13%/day. Although the growth rate at the nominal ration level of 18%/day was less than at 13%/day, the difference was small. This may be explained by the fact that the actual consumption rates were similar at the two highest ration levels. The actual consumption rates were 11.91 and 13.51%/day at the nominal ration ration levels of 13 and 18%/day, respectively. Figure 12 shows that the highest growth rates were recorded at the nominal temperature of 13.5 C and at the highest ration levels (13 and 18%/day). The curves relating temperature and growth at the highest ration levels were nearly alike. Again this may be a result of the similarity in actual consumption rates at these ration levels. The actual consumption rates were 12.75 and 14.91%/day for the nominal ration levels of 13 and 18%/day, respectively.

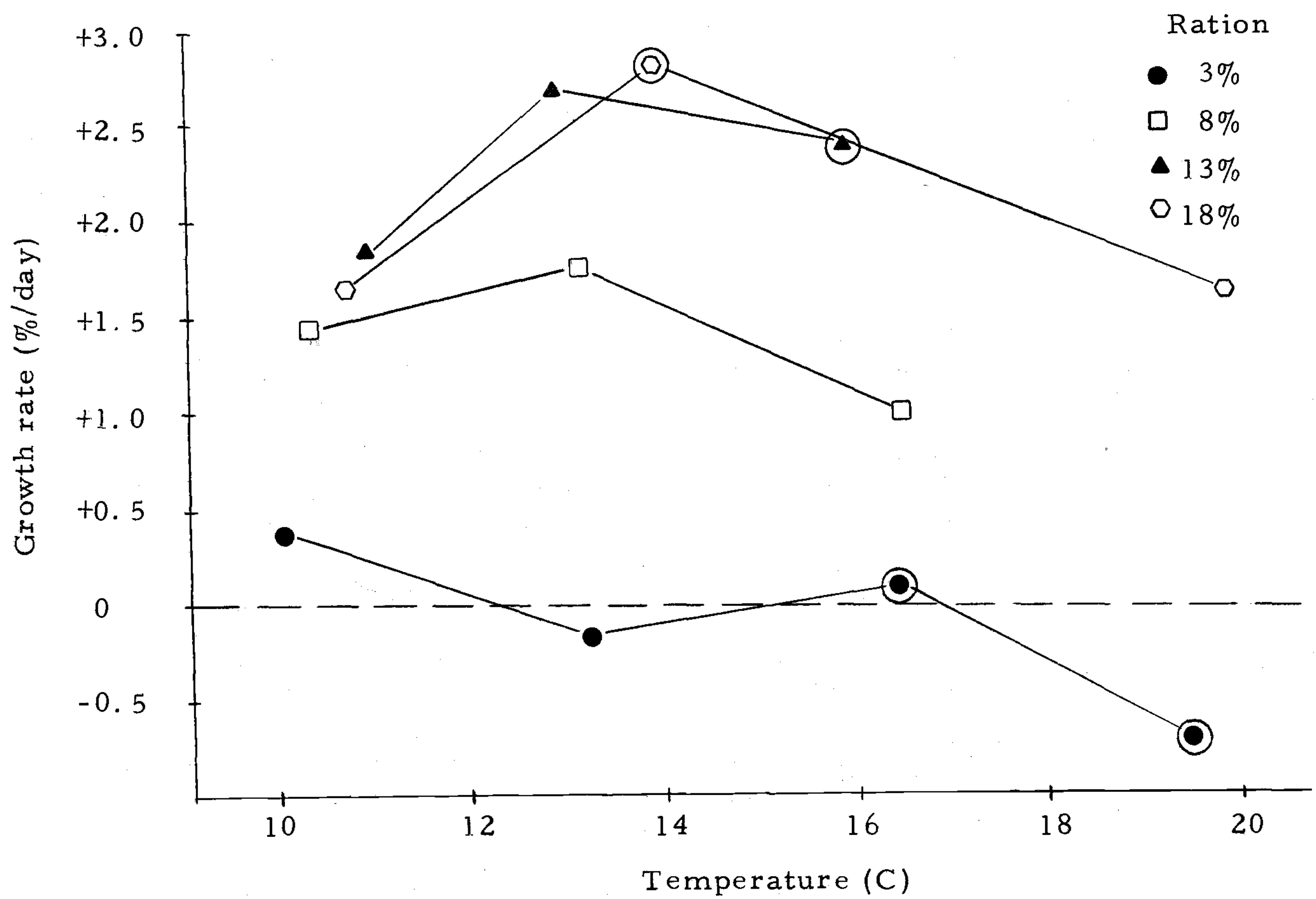

Figure 12. Relationships between temperature and rate of growth of chum salmon fed at four ration levels during experiment II. Circled points are based upon a sample of fewer than 20 fish during the second 14-day sampling period.

Values of growth rate in experiment II were generally higher than in experiment I. This is assumed to be the result of increased ration levels in the second experiment. The fish were not fed to repletion in experiment I and most of the rations fed at a given temperature were below maintenance levels, whereas in experiment II, most of the rations fed were above maintenance levels.

As with growth, food conversion efficiencies were generally higher in experiment II than in experiment I. This reflects the decrease in maintenance rations during the second experiment. A smaller proportion of the food consumed was required just to maintain the fish, and a greater proportion was available for growth than during the first experiment.

Food conversion efficiencies were again dependent on both ration level and temperature (Figure 13). At the two lowest temperatures (11.0 and 13.5 C), food conversion efficiencies increased with increases of ration level (3 to 8%/day), and then began to decline. At the two highest temperatures, food conversion efficiencies continued to increase with an increase in ration. The highest efficiencies were recorded at the three highest ration levels (8, 13, and 18%/day) and at 13.5 C (Figure 14). At a ration level of 3%/day, food conversion efficiencies decreased with an increase in temperature. At the higher ration levels, the fish were able to utilize more efficiently

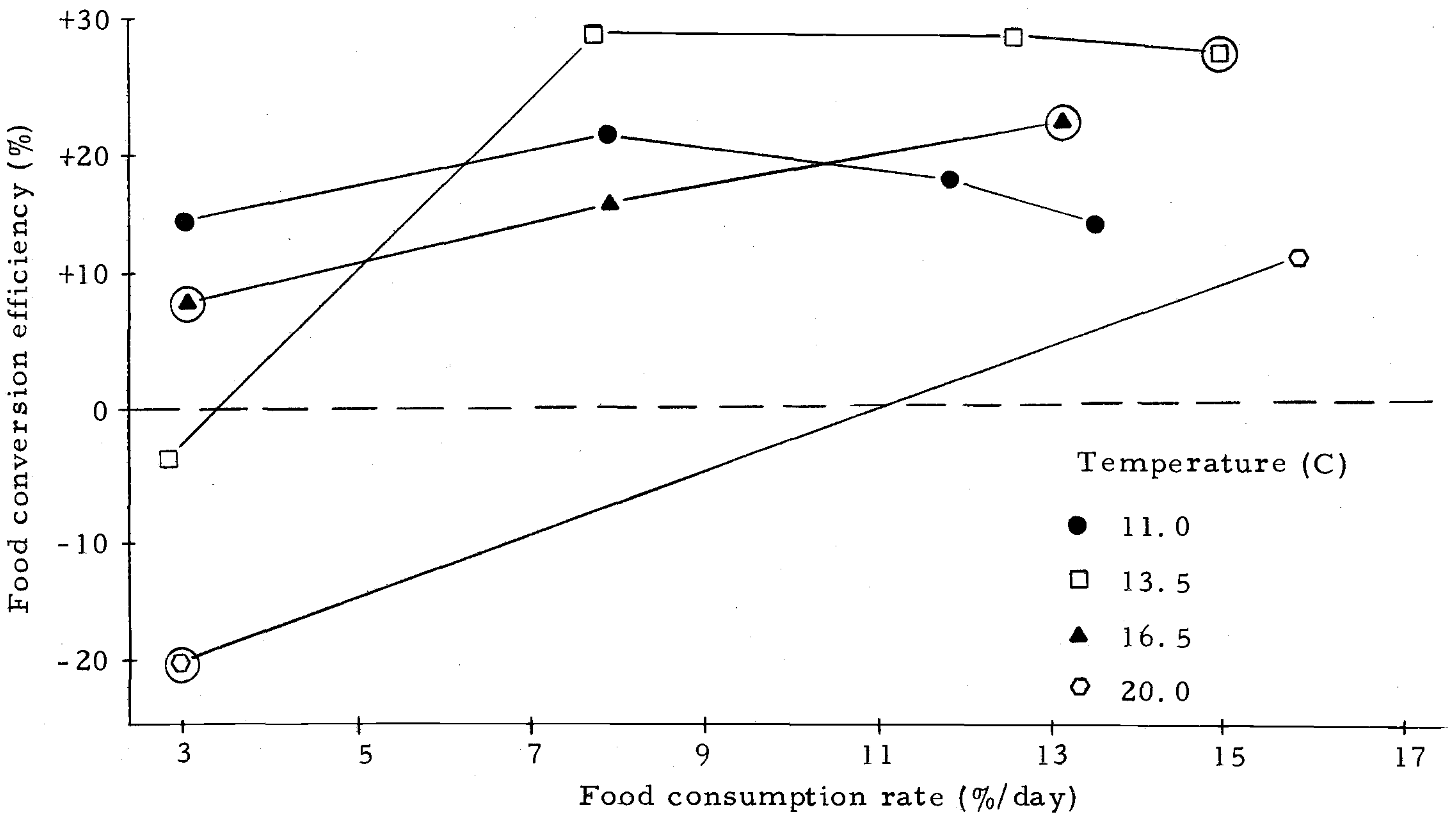

Figure 13. Relationships between food consumption rate and food conversion efficiency of chum salmon kept at different temperatures during experiment II. Circles points are based upon a sample of fewer than 20 fish during the second 14-day sampling period.

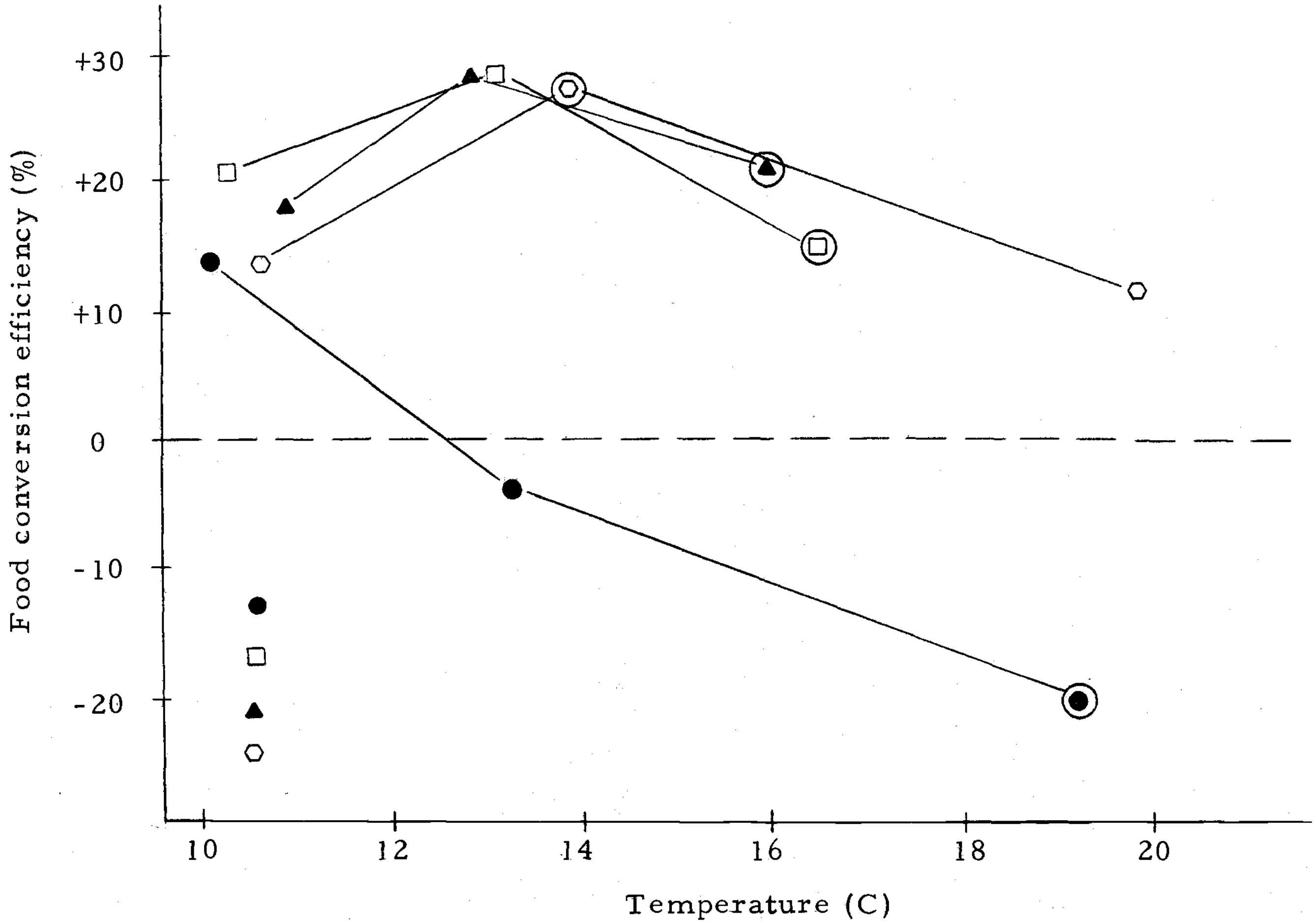

Figure 14. Relationships between temperature and food conversion efficiency of chum salmon fed at four ration levels during experiment II. Circled points are based upon a sample of fewer than 20 fish during the second 14-day sampling period.

the food for growth over a wider range of temperatures than at the lower ration levels.

The number of deaths resulting from Vibrio disease was generally highest at the highest temperatures (Figure 15), totalling 6.4, 23.4, 40.4, and 36.2% at 11.0, 13.5, 16.5, and 20.0 C, respectively. Unlike experiment I, mortality rates during this experiment did not show a clear relationship with ration level. This may be because even the lowest ration levels were in excess of maintenance for all but the highest temperature treatments (compare Figures 5 and 11), so that low ration was a less significant factor in experiment II than in experiment I.

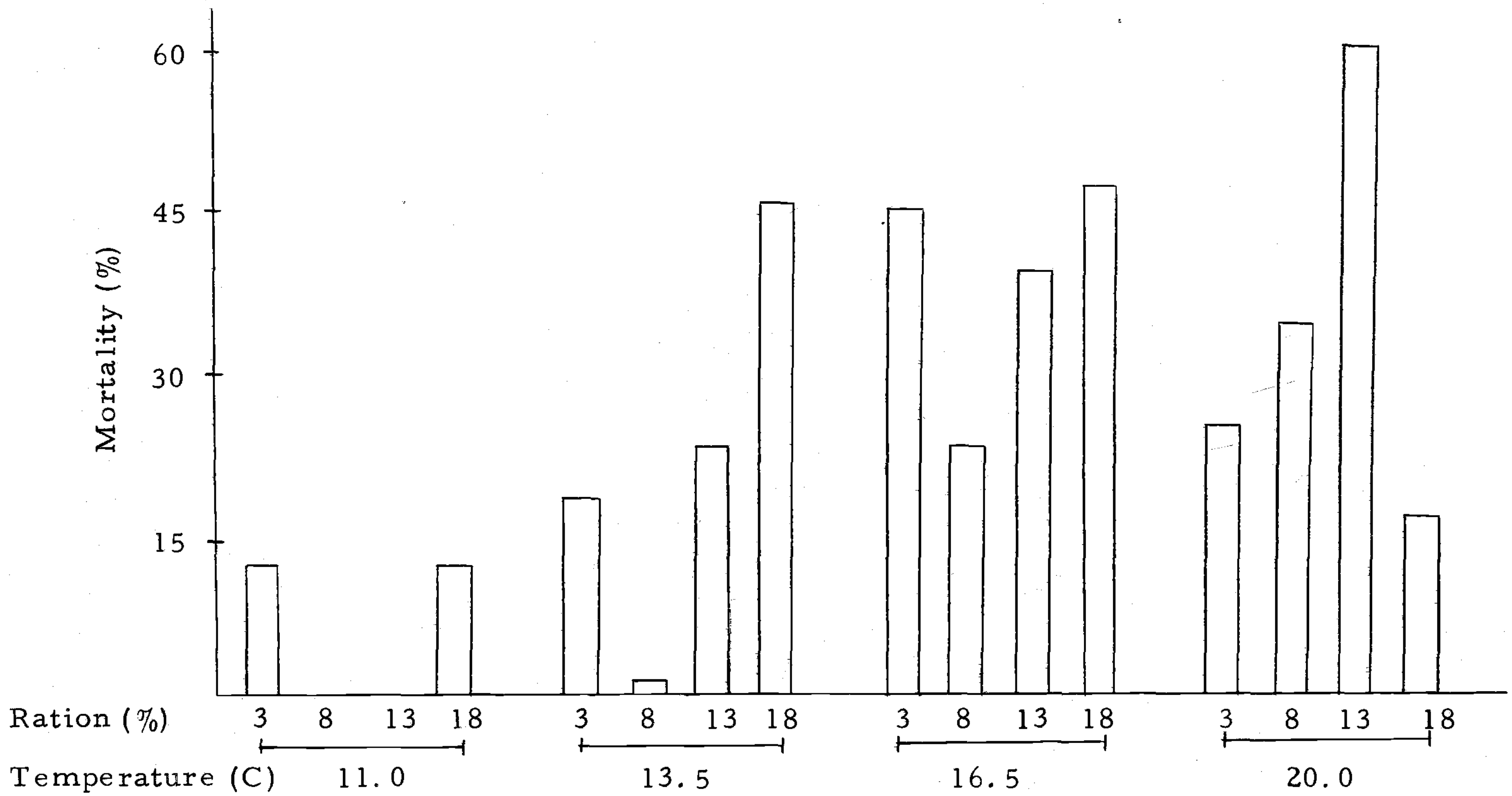

Figure 15. Mortality rates of chum salmon, kept at different temperatures and ration levels during experiment II, which were attributed to Vibrio disease.

IV. DISCUSSION AND CONCLUSIONS

Growth rates have been shown to be influenced both by temperature and the amount of food the fish consume. The results of these experiments showed that growth and food conversion efficiency of chum salmon was better at 13.5 C than at 11.0 and 16.5 C when the fish were fed to satiation. Maximum growth has been reported to occur between 14.5 and 15.5 C for several species of salmon and trout (Banks et al., 1971; Brett et al., 1969; Baldwin, 1957). This coincides with a general physiological optimum temperature which allows greatest tolerance to oxygen debt, maximum sustained swimming speed, and maximum metabolic activity (Brett et al., 1969). Although the results of the present studies with chum salmon cannot be directly compared with those reported for salmonids reared in freshwater and fed on different diets and ration levels, it appears likely that the effects of elevated temperature on chum salmon are not greatly different from those reported for other salmonids.

Preliminary studies carried out at the Port Orford Marine Research Laboratory, Oregon State University, indicated that chum salmon kept at salinities of 32-35 o/oo, and fed to satiation on the Oregon Moist pellet grew satisfactorily at temperatures as high as 18.3 C (Robert Malouf, personal communication). The generally poor growth of chum salmon kept at elevated temperatures in my experiments probably can be attributed, at least in part, to the high incidence of Vibrio disease. The effects of disease on fish growth have not been studied, but it is generally assumed that the efficiency of food utilization in diseased fish is lower than in healthy fish. Since salmonid diseases are generally more virulent at higher temperatures (Ordal and Pacha, 1963), it is likely that growth was suppressed at the highest temperatures where the incidence of Vibrio disease was greatest.

Small reductions of dissolved oxygen concentrations from air saturation values during experiment II (Appendix I) may have influenced growth rates, but probably not significantly. Hermann et al. (1962), studying age group one coho juveniles, found that growth rates declined only slightly with reductions in oxygen concentrations from a mean of about 8.3 to 5.0 mg/l, and food conversion efficiencies were only slightly depressed at concentrations near 4 mg/l. The general conclusions with regard to the most favorable temperature for growth probably would not be influenced since some reductions of oxygen concentrations were recorded at all test temperatures. The same general conclusions regarding favorable temperatures for growth were derived from the results of the first experiment, in which case oxygen levels were near saturation (Appendix I).

Seasonal differences have been reported to have an effect on the relationship between temperature, food consumption, and growth of fish (Averett, 1969; Wurtsbaugh, 1973). The growth rates of the chum salmon were markedly greater during the fall (Experiment II) than during the spring-summer season (Experiment I), but any influence of season on the growth of the fish cannot be confirmed, since the sizes of fish and the ration levels employed during experiment I were different from those of experiment II.

The smaller values of growth rate and food conversion efficiency recorded during both experiments at 11 C than at 13.5 C may have been influenced by the fluctuating temperatures which occurred in the tanks kept nominally at 11.0 C. Everson (1973) compared the growth rates and food conversion efficiencies of juvenile coho salmon kept at fluctuating temperatures with those kept by Averett (1969) at constant temperatures. He showed that growth rates and food conversion efficiencies of fish kept at moderate constant temperatures (15.5 C) were somewhat greater than those values obtained for fish exposed to temperatures that fluctuated about a similar mean value of 15.6 C.

The results of the study suggest that the elevation of sea water temperatures beyond approximately 13.5 C does not benefit the growth of chum salmon. The extent to which the relationships between rates of growth and food consumption of chum salmon were influenced by Vibrio disease is not known. Given that methods can be devised for the control of Vibriosis, the growth and food relationships of the fish at elevated temperatures (above 14 C) should be verified. Additionally, further studies should be undertaken to evaluate the beneficial uses of heated sea water for the culture of chum salmon during seasonally cold periods of the year.

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APPENDICES

APPENDIX I

Test temperatures and values of dissolved oxygen concentration, pH, and salinity recorded for the different nominal temperature and ration levels during experiments I and II.

Experiment I

Nominal Temperature (C)	Nominal Ration (%/day)	Actual Temperature (C)			Dissolved Oxygen Concentration (mg/1)			pH			Salinity ($^o/oo$)		
		Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean
11.0	3	10.1	15.8	11.9	8.20	9.00	8.80				31.6	34.1	33.2
	6	10.3	15.8	12.3	8.25	8.95	8.75						
	9	10.7	14.7	12.2	8.20	8.95	8.75						
	15	10.1	14.4	11.7	8.05	8.95	8.70						
13.5	3	13.2	15.7	13.9	8.20	8.60	8.40						
	6	13.2	15.7	13.8	8.20	8.55	8.40						
	9	13.1	15.7	13.7	8.10	8.55	8.40						
	15	13.0	14.9	13.5	7.80	8.65	8.35						
16.5	3	16.2	16.9	16.5	7.50	8.10	7.95						
	6	16.2	16.9	16.6	7.80	8.00	7.90						
	9	16.3	16.9	16.6	7.85	8.05	7.95						
	15	16.3	16.9	16.7	7.50	8.05	7.95						
20.0	3	18.1	19.9	19.6	7.10	7.70	7.50						33.3
	6	18.2	20.4	19.8	7.30	7.60	7.45						33.3
	9	17.3	19.9	19.6	7.45	7.70	7.55						32.2
	15	16.6	20.0	19.4	7.20	7.65	7.40						33.2

APPENDIX I. (Continued)

Experiment II

Nominal Temperature (C)	Nominal Ration (%/day)	Actual Temperature (C)			Dissolved Oxygen Concentration (mg/1)			pH			Salinity (°/oo)		
		Low	High	Mean	Low	High	Mean	Low	High	Mean	Low	High	Mean
11.0	3	9.3	12.0	10.2	7.10	8.55	7.60	7.80	7.95	7.85	32.1	33.8	32.8
	8	9.4	11.8	10.4	6.75	8.50	7.30	7.70	7.96	7.85			
	13	9.4	12.4	10.9	6.20	7.40	6.40	7.70	7.94	7.80			
	18	9.6	12.4	10.8	6.20	8.55	6.55	7.70	7.94	7.78			
13.5	3	12.6	14.2	13.3	6.90	8.20	7.40	7.80	7.98	7.89			
	8	12.8	14.3	13.2	6.30	7.65	6.30	7.70	7.94	7.84			
	13	11.2	14.3	12.8	6.60	8.85	7.60	7.70	7.85	7.78			
	18	13.3	14.3	13.9	6.70	7.90	7.00	7.70	7.93	7.81			
16.5	3	15.7	16.7	16.5	6.70	8.00	7.30	7.70	7.96	7.85			
	8	15.9	16.7	16.5	6.00	8.40	6.95	7.70	7.98	7.83			
	13	14.8	16.7	16.0	6.85	8.00	6.50	7.70	8.04	7.88			
	18	15.1	16.7	16.2	6.20	7.00	6.10	7.70	7.70	7.70			
20.0	3	18.1	20.1	19.4	6.25	8.15	7.15	7.70	8.00	7.87			
	8	18.6	20.3	19.8	6.05	7.30	6.65	7.70	7.90	7.80			
	13	15.9	20.0	18.8	6.85	7.90	7.35	7.70	7.90	7.80			
	18	18.8	20.1	19.9	6.00	7.35	6.20	7.70	7.90	7.80			

APPENDIX II

Average lengths, wet weights, and dry weights of chum salmon kept at different ration levels and temperatures for each sampling period during experiments I and II. The numbers in parenthesis indicate sample sizes when fewer than 20 fish were available.

Experiment I

		Initial Sample			10-Day Sample			20-Day Sample			30-Day Sample			Final Sample		
Nominal Temperature (C)	Nominal Ration (%/day)	Length (cm)	Wet Wt. (g)	Dry Wt. (g)	Length (cm)	Wet Wt. (g)	Dry Wt. (g)	Length (cm)	Wet Wt. (g)	Dry Wt. (g)	Length (cm)	Wet Wt. (g)	Dry Wt. (g)	Length (cm)	Wet Wt. (g)	Dry Wt. (g)
11.0	3	5.12	1.03	0.18	5.06	0.92	0.13	5.30	1.04	0.16	5.44	1.02	0.14	5.44 (5)	1.00	0.16
	6	5.55	1.31	0.23	5.53	1.27	0.19	5.46	1.17	0.17	5.79	1.41	0.19	5.60	1.12	0.18
	9	5.20	1.04	0.20	5.41	1.23	0.19	5.54	1.32	0.21	5.69	1.42	0.22	5.75	1.43	0.22
	15	5.21	1.07	0.19	5.57	1.30	0.20	5.75	1.53	0.27	6.22	1.98	0.33	6.52	2.33	0.42
13.5	3	5.66	1.39	0.22	5.70	1.32	0.24	5.86	1.36	0.23	5.73	1.15	0.18	5.90 (1)	1.23	0.18
	6	5.51	1.31	0.23	5.57	1.29	0.21	5.44	1.16	0.21	5.67	1.27	0.21	5.70 (15)	1.36	0.21
	9	5.20	1.10	0.19	5.51	1.26	0.19	5.56	1.32	0.22	5.81	1.43	0.25	5.89	1.53	0.24
	15	5.26	1.09	0.19	5.48	1.31	0.21	5.99	1.75	0.29	5.96	1.69	0.31	6.34	2.19	0.39
16.5	3	5.80	1.42	0.25	5.13	0.90	0.14	5.55	1.00	0.13	5.45 (5)	0.98	0.15			
	6	5.48	1.24	0.21	5.40	1.12	0.17	5.33	0.94	0.15	5.60	1.07	0.18	5.81 (7)	1.25	0.20
	9	5.43	1.21	0.19	5.60	1.28	0.20	5.64	1.18	0.20	5.67	1.27	0.18	5.71 (12)	1.27	0.20
	15	5.36	1.18	0.19	5.71	1.44	0.25	5.75	1.51	0.25	5.92	1.71	0.27	6.03	1.85	0.33
20.0	3	4.92	0.88	0.16	5.21	0.90	0.14	5.57 (15)	0.99	0.16						
	6	5.38	1.17	0.23	5.53	1.16	0.20	5.93 (4)	1.34	0.24						
	9	5.43	1.20	0.21	5.32	1.07	0.18	5.44	1.11	0.18	5.52 (11)	1.17	0.18			
	15	5.31	1.12	0.19	5.50	1.26	0.22	5.61	1.26	0.19	5.69	1.31	0.20	6.16 (17)	1.78	0.31

APPENDIX II. (Continued)

Experiment II

Nominal Temperature (C)	Nominal Ration (%/day)	Initial Sample Length (cm)	Initial Sample Wet Wt. (g)	Initial Sample Dry Wt. (g)	14-Day Sample Length (cm)	14-Day Sample Wet Wt. (g)	14-Day Sample Dry Wt. (g)	28-Day Sample Length (cm)	28-Day Sample Wet Wt. (g)	28-Day Sample Dry Wt. (g)	Final Sample Length (cm)	Final Sample Wet Wt. (g)	Final Sample Dry Wt. (g)
11.0	3	11.17	12.33	2.51	11.10	11.85	2.27	11.78	14.07	2.77	11.99	14.81	2.90
	8	11.25	12.61	2.57	11.90	15.78	3.31	12.26	17.84	3.77	13.36	23.76	5.26
	13	11.28	12.48	2.57	11.58	14.60	3.11	12.56	19.32	4.16	13.46	24.99	5.67
	18	11.42	12.94	2.65	11.76	15.28	3.25	12.26	18.90	4.12	13.61 [16]	24.53	5.82
13.5	3	11.49	13.44	2.61	11.24	12.15	2.33	11.63	13.06	2.51	11.93 [14]	14.59	2.77
	8	11.21	12.43	2.40	11.85	14.97	3.50	12.34	18.26	3.85	13.39	23.45	4.84
	13	11.17	12.09	2.54	12.02	17.04	4.20	13.22	23.13	5.26	14.41 [19]	30.23	6.84
	18	11.14	12.39	2.58	11.57	14.73	3.32	13.70 [15]	25.33	5.49			
16.5	3	10.92	11.47	2.38	11.12	11.31	2.13	11.17 [16]	12.50	2.47			
	8	11.15	12.23	2.50	11.29	13.86	2.85	11.61	15.40	3.31	12.66 [8]	19.62	4.64
	13	10.83	11.36	2.26	11.39	14.20	3.02	12.83 [13]	21.06	4.33			
	18	10.75	11.15	2.17	11.73	15.71	3.33						
20.0	3	11.16	12.84	2.59	11.29	11.46	2.33	11.40 [9]	10.94	2.21			
	8	10.94	11.38	2.42	11.21	11.42	2.20						
	13	11.18	12.64	2.34	11.76 [14]	14.83	3.26						
	18	10.74	11.32	2.03	11.07	12.96	2.67	11.79	15.83	3.16	12.01 [13]	17.26	3.68

APPENDIX III

Average relative rates of food consumption and growth, and food conversion efficiencies of chum salmon kept at different ration levels and temperatures during experiments I and II. Values are based upon dry weights of food and fish. The numbers in parenthesis indicate sample sizes when fewer than 20 fish were available.

Experiment I

Mean Temperature (C)	Nominal Ration (%/day)	Growth Rate (%/day) Sample Period (days) 1-10	11-20	21-30	31-40	Consumption Rate (%/day) Sample Period (days) 1-10	11-20	21-30	31-40	Conversion Efficiency (%) Sample Period (days) 1-10	11-20	21-30	31-40
11.9	3	-3.15	2.07	-1.77	1.62 (5)	3.12	3.07	3.17	4.32	-88.74	74.52	-51.78	37.88
12.3	6	-1.94	-1.12	1.05	-0.94	5.85	6.09	6.00	6.16	-30.54	-17.56	18.43	-14.63
12.2	9	-0.37	0.73	0.88	-0.36	8.86	9.10	8.99	8.97	-4.09	8.35	10.19	-3.99
11.7	15	0.42	3.03	2.49	2.47	15.13	15.21	14.82	15.08	2.84	23.12	18.89	18.42
13.9	3	0.66	-0.22	-2.83		3.19	3.01	3.49		21.37	-7.33	-71.52	
13.8	6	-1.03	-0.23	0.36	0.04 (15)	5.89	6.03	6.17	6.71	-16.80	-3.72	5.92	0.63
13.7	9	0.04	1.94	1.44	-0.64	9.55	9.18	8.87	9.50	0.44	23.13	17.45	-6.64
13.5	15	0.74	3.79	0.81	2.40	14.44	15.17	14.90	14.84	5.22	30.19	5.67	18.16
16.5	3	-6.55	-0.39	1.68 (5)		3.10	3.24	5.38		-163.44	-11.63	30.92	
16.6	6	-2.70	-1.18	1.72	1.14 (7)	6.00	6.09	6.82	6.60	-40.13	-18.43	27.17	18.29
16.6	9	0.51	-0.24	-0.67	1.16 (12)	9.13	9.17	9.76	10.85	5.78	-2.62	-6.69	11.23
16.7	15	2.94	0.33	0.72	2.35	15.03	14.78	15.09	15.16	22.56	2.25	4.94	17.29
19.6	3	-1.34	0.93 (15)			3.18	3.32			-39.81	28.23		
19.8	6	-1.62	2.04 (4)			6.65	7.12			-22.31	31.10		
19.6	9	-2.19	0.36	-0.45 (11)		10.44	9.44	12.19		-19.07	3.82	-3.49	
19.4	15	1.54	-1.19	0.05	5.19 (17)	14.59	15.19	15.70	14.84	11.33	-7.44	0.36	46.27

APPENDIX III. (Continued)

Experiment II

Mean Temperature (C)	Nominal Ration (%/day)	Growth Rate (%/day) Sample Period (days)			Consumption Rate (%/day) Sample Period (days)			Conversion Efficiency (%) Sample Period (days)		
		1-14	15-28	29-42	1-14	15-28	29-42	1-14	15-28	29-42
10.2	3	-0.76	1.51	0.35	2.99	3.02	4.19	-26.07	55.69	8.61
10.4	8	1.93	1.01	2.54	8.15	7.67	9.90	29.36	14.19	30.68
10.9	13	1.46	2.22	2.37	12.70	11.07	13.62	13.71	23.45	20.54
10.8	18	1.55	1.82	2.62 (16)	14.54	12.41	12.83	12.85	16.66	24.36
13.3	3	-0.89	0.57	0.77 (14)	3.00	2.78	4.58	-30.29	21.17	17.39
13.2	8	2.87	0.73	1.75	8.19	7.58	9.91	46.64	10.13	19.97
12.8	13	3.79	1.73	2.00 (19)	13.27	12.33	11.96	41.09	15.76	18.39
13.9	18	1.92	3.79 (15)		15.44	12.24		15.39	40.41	
16.5	3	-0.85	1.14 (16)		3.09	2.82		-26.79	43.67	
16.5	8	1.00	1.16	2.56 (8)	8.15	7.74	12.54	14.34	16.18	24.01
16.0	13	2.21	2.75 (13)		13.38	12.62		20.97	24.47	
16.2	18	3.25			17.58			24.09		
19.4	3	-0.81	-0.39 (9)		3.04	2.93		-27.22	-12.89	
19.8	8	-0.72			7.59			- 9.67		
19.8	13	2.24 (14)			13.35			19.58		
19.9	18	2.09	1.28	1.17 (13)	16.98	14.46	19.29	15.34	9.72	6.55

APPENDIX IV

Numbers of deaths of chum salmon and percentages of mortality attributed to Vibrio disease at different temperatures and ration levels. Initial numbers of fish at each temperature and ration level were 120 and 94 for experiments I and II, respectively. The duration of experiment I was 40 days; that of experiment II was 42 days.

Experiment I				Experiment II			
Mean Temperature (C)	Consumption Rate (%/day)	Number of Deaths	Percentage Mortality	Mean Temperature (C)	Consumption Rate (%/day)	Number of Deaths	Percentage Mortality
11.9	3.19	34	28.33	10.2	3.23	12	12.77
12.3	5.97	4	3.33	10.4	8.43	0	0.00
12.2	8.97	0	0.00	10.9	12.39	0	0.00
11.7	15.06	0	0.00	10.8	13.35	12	12.77
13.9	3.26	33	27.50	13.3	3.19	18	19.15
13.8	6.08	14	11.67	13.2	8.42	1	1.06
13.7	9.28	6	5.00	12.8	12.59	23	24.47
13.5	14.82	0	0.00	13.9	14.91	46	48.94
16.5	3.24	53	44.17	16.5	3.04	43	45.75
16.6	6.19	24	20.00	16.5	8.54	23	24.47
16.6	9.38	27	22.50	16.0	13.09	40	42.55
16.7	14.99	0	0.00	16.2	17.58	46	48.94
19.6	3.22	52	43.33	19.4	3.00	26	27.67
19.8	6.72	63	52.50	19.8	7.59	36	38.29
19.6	10.30	39	32.50	18.8	13.35	57	60.64
19.4	15.03	12	10.00	19.9	16.47	17	18.85