THE EFFECT OF TEMPERATURE AND DIET ON THE GROWTH OF JUVENILE COHO SALMON (ONCORHYNCHUS KISUTCH)

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

TERRY R. CULP

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THESIS

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ABSTRACT

THE EFFECT OF TEMPERATURE AND DIET ON THE GROWTH OF JUVENILE COHO SALMON *(ONCORHYNCHUS KISUTCH)*

By

Terry R. Culp

Three different temperatures (12 ± 0.5, 14 ± 0.5 and 17 ± 0.5 C), and two different diets fed in excess (Oregon moist and Ewos), were tested to measure their effect on the growth of juvenile coho salmon. Maximum growth occurred with the Oregon moist diet at a temperature of 14.5 C, and growth was greater for fish fed Oregon moist at all temperatures when compared to fish fed Ewos at the same temperatures. Mortality, growth, and body composition (water, fat, and ash) were measured at 10 day intervals from the time fish started to feed until the fish showed definite signs of smolting (160 days). Percent protein was measured in fish taken on the final sampling period. Mortality was higher, and fat content lower, for fish fed the Ewos diet at all temperatures tested. Within the first 20 days of the experiment the fish fed Oregon moist obtained a higher proportion of body fat then those fed Ewos, and they retained this higher proportion throughout the experiment, though the fat content of all fish increased with time independent of the diet fed.

Terry R. Culp

Maximum food consumption and digestion rate (gastro-intestinal motility) were measured at two different temperatures (13 ± 0.5 and 16 ± 0.5 C), using each of the two diets. At both temperatures fish fed Oregon moist consumed more in proportion to total body weight, and exhibited a faster rate of digestion than fish fed Ewos.

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(ONCORHYNCHUS KISUTCH)

By

Terry R. Culp

A THESIS

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Dedicated to my parents.

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The writer is grateful to Mr. Henry Dunn who built much of the equipment used in the experiment.

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INTRODUCTION

With the growing need of particular fish species for both food and recreation, and the limited ability of the environment to support and produce these species, much effort in recent years has been put forth in the artificial propagation of economically important fish species. Because of this there has developed much concern and controversy over the variety of factors that have been shown to effect fish growth. That there are a great many variables effecting fish growth has been well documented (Warren, 1971; Brown, 1957; Warren and Davis, 1956), yet the exact priority as to importance of each of these factors is still being debated. Certainly temperature can be agreed upon as being one of the most influential environmental factors effecting the growth of fishes (Brett, Shelbourn and Shoop, 1969; Markus, 1962; Baldwin, 1957; Brown, 1957; Haskell, Wolf and Bouchard, 1956; Donaldson and Foster, 1940). Along with temperature the quality and quantity of a fish's diet is an important determinant of growth (Brett et al., 1969; Locke and Linscott, 1969). Brett et al. (1969) looked at the combined effects of both temperature and diet on growth, and defined specific temperatures for optimum growth in sockeye salmon. They stated that there is enough evidence for the success of environmental and ration control as a means of maximizing growth to predict that the production of any species of fish which is amenable to artificial culture could be improved.

The optimum environmental and dietary conditions for growth have been determined for various species of the family *Salmonidae* and from these data it should be possible to predict the optimum conditions for growth of a salmonid species even where specific data is lacking. Certainly with the economic importance of coho salmon (*Oncorhynchus kisutch*) and the increasing importance of the coho salmon in the Great Lakes fishery, information on the optimum conditions for growth would be important for coho culture.

Coho are usually stocked as smolts to insure maximum survival in their natural environment, thus manipulation of growth factors to reduce the time till smolting would be warranted, provided fish quality would not be sacrificed in the process. Since several physiological parameters associated with smolting in salmonids have been shown to be mainly a function of size, with age being of minor importance (Johnston and Eales, 1970; Vanstone and Market, 1968; Conte et al., 1966; Houston, 1961; Elson, 1957; Allen, 1944), any of the factors favorably effecting coho growth should also reduce the time till smolting.

The purpose of the present study was to determine methods for maximizing growth of coho salmon through manipulation of temperature and diet. The specific objectives of the study were:

1. To determine the optimum temperature for growth of coho salmon.
2. To compare effectiveness of a dry diet vs. a wet diet in promoting growth of coho salmon.
3. To determine the food consumption and rate of digestion (gastro-intestinal motility) for each of the different diets.

MATERIALS AND METHODS

The experiment was conducted from February 7, 1971 until July 17, 1971, a period of 160 days.

The coho salmon used in this experiment were shipped from the state of Oregon as eyed-eggs, and hatched in tray incubators (Heath Techna Plastics, Kent, Washington) in the laboratory. The eggs (5,000) were incubated at 11 C and mortality up until fry swim-up was very low (less than 1%). The eggs represented a heterogeneous genetic stock, having been a sample obtained from many females. The fish were transferred from the incubators to rearing tanks at the swim-up fry stage. A total of 650 fry were placed in each of six rearing tanks where they were held throughout the remainder of the experiment. The average length of the fry at this time was 3.2 cm based on a sample of 25 fish.

Rearing Conditions

The rearing tanks were 197 liter (43 gal) oval shaped units equipped with a central stand pipe, and covered with one-half inch mesh screen. Each tank was supplied with water from a series of 3 mixing tanks where hot and cold water supplies were mixed to provide the desired test temperatures. The cold water (average temperature 12 C) was supplied to a 1145 liter (250 gal) reservoir which in turn supplied water to each of the three 92 liter (20 gal) mixing tanks. Hot water (average temperature 65 C) from a glass-lined water heater was supplied directly to the mixing tanks in sufficient volume to provide the desired test temperature. Each mixing tank supplied water for each of two rearing tanks by equally dividing the flow. After the fry were transferred to the rearing tanks the water temperatures were gradually increased by 2 C increments daily until the test temperatures of 12, 14, and 17 C were attained. Because of some fluctuations in hot water temperatures, and a gradual seasonal increase in cold water temperatures, periodic adjustment in the proportions of hot and cold water were necessary during the experiment. Water temperatures were recorded daily from thermometers held in each tank. The average water temperature for each rearing condition during the 160 day period was 12 ± 0.5, 14 ± 0.5 and 17 ± 0.5 C.

The water entered the rearing tanks from a pipe on the side, which created a slight circular current in the tanks and the fish seemed to orient to this. The exchange rate for the experimental tanks also varied due to manipulation of the amounts of hot and cold water, but generally ranged between 90-120 gal per hr. The amount of water delivered to tanks with duplicate temperature was always equal, since they were both being fed from the same mixing tank.

The water used in these experiments was Michigan State University tap water which was passed through an activated carbon filter to remove residual chlorine. The chemical properties of this water are given in Appendix A.

Head tanks and rearing tanks were oxygenated by compressed air pumped through air-stones. Periodic measurement showed dissolved oxygen (DO) was above 7 ppm in all tanks except on two occasions when the concentration dropped to 6 ppm in one 17 C tank. This decline was probably due to an accumulation of uneaten food which would have a high BOD in the warmer water.

The fish were maintained in constant light. Eisler (1957) working with salmon and Pyle (1969) with trout showed that growth was best with constant light. The light for the experiment was supplied by placing two 50 watt bulbs approximately 10 ft above the tanks providing uniform illustration to all tanks.

Both smolting (Hoar, 1965) and fish growth (Gross et al., 1965) were shown to be enhanced by increasing photoperiod. Windows at the front and the rear of the room allowed a naturally seasonal increase in photoperiod.

Food

The two diets tested in the experiment were a dry feed, Ewos (Aktiebolaget Ewos Co., Sodertalje, Sweden), and a moist feed, Oregon moist (Astoria Seafoods Lab., Astoria, Oregon), both thought to provide excellent growth in coho salmon. The composition of the two diets is given in Appendix B. The Oregon moist pellets were obtained from the Michigan Department of Natural Resources and the Ewos diet was obtained from the manufacturer.

The Ewos diet is a completely dry diet developed for Atlantic salmon by Aktiebolaget Ewos of Sodertalje, Sweden. It contains fish protein concentrate products. Its fat content is primarily cod-liver oil, for it is believed that this poikilothermic animal fat is more easily used than vegetable fats due to its lower melting point. Ewos nutritionists feel that fairly high fat levels are desirable in a fish food when the fat is easily assimilated by fish (Locke and Linscott, 1969).

The Oregon moist diet was developed by the Oregon Fish Commission and Astoria Seafoods Laboratory, an agricultural experiment station of OREGON State College. It was developed for Pacific salmon culture, and contains high fat and protein levels (Hablou, Wallis, McKee, Law, Sinnhuber and Yu, 1958).

The particle size of the food varied as the fish grew larger, and often particles of different size were mixed. Three different size particles were fed. Fish fed Ewos were fed "Ewos Starter F48" (particle size 0.01-0.03 in), until the fish reached a size of 1.5 in, then they were transferred to "Ewos Grower F49," size number 2 (particle size 0.03-0.06 in), until they reached a size of approximately 1.6-2.8 in. From this size until the end of the experiment they were fed size number 3 of "Ewos Grower F49" (particle size 0.06-0.08 in). Fish on Oregon moist were fed "Oregon Moist Starter" and then particle sizes 0.03 in and 0.09 in. Adjustment in particle size was made at the same time for each diet.

Method of Feeding

The food was administered to each test tank by automatic feeders constructed for this experiment. Each feeder consisted of a cone-shaped hopper with a rotating blade at the bottom. An electric motor connected to a timer device caused the blade to rotate slowly for 15 min every hr. The rotating blade pushed a small amount of food out the bottom of the feeder and into the test tank. One feeder was positioned above each tank. The size of the feeder opening was adjusted to control the amount of food fed.

Immediately after the fry were transferred to the rearing tanks food was provided manually many times each day to encourage feeding among all groups. On February 7, when at least 50% of all fish appeared to be feeding the experiment was initiated and the automatic feeders used. During the first 20 days the fish were fed 24 times each day with excess food available at all times. On the 20th day a sample of 20 fish was taken and from this wet wt an amount of food equal to 10% body weight was determined. This was approximately 1.6-2.8 in. From this size until the end of the experiment they were fed size number 3 of "Ewos Grower F49" (particle size 0.06-0.08 in). Fish on Oregon moist were fed "Oregon Moist Starter" and then particle sizes 0.03 in and 0.09 in. Adjustment in particle size was made at the same time for each diet.

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On April 28, the amount of food fed was changed to 7% of body weight, since as the fish grew larger less food was being consumed. This fits well with Bretts' (1971) data, which showed that the amount of food consumed by sockeye salmon in proportion to the total body wt decreased as the fish grew larger.

Sampling Procedure

Samples of 20 fish were removed every 10 days from an initial stock of 650 fish. When the screen covers were removed the fish tended to congregate in the rear of the tanks. A sample of 20 fish was then caught by drawing a dipnet vertically through the group. The fish were then killed by overanaesthetizing with approximately 150 ppm MS 222 and blotted dry. Total length and weight measurements were taken to the nearest 0.1 cm and 0.01 g. The fish were then wrapped in foil and placed in a freezer for later analysis of fat, water and ash.

Proximate Analysis

Water, fat and ash content were determined on each sample taken. Protein was determined in samples taken at the conclusion of the growth experiment. Carbohydrate was not determined for this constituent is believed to be no more than 0.5% of body weigt (Vinogradov, 1953; Black, 1958).

Each sample was prepared for analysis by grinding it to a fine homogenate in a blender. A subsample (10-15 g) was then placed in a tared aluminum pan and dried in an oven at 105 C for 24 hrs. The water content was determined by subtracting dry weight from wet weight. The dried sample was then extracted in hexane according to the method given by Brett et al. (1969), Appendix C, and the residue weighed to determine fat content. Ash weight was determined on the remaining residue by the methods described in the "Association of Official Analytical Chemists (1960)," Appendix D.

Percent protein was only measured in samples taken on July 17, since it is closely related to ash and fat content (Phillips et al., 1963). For samples taken July 17 the percent of nitrogen in each sample was determined by "Perkin-Elmer Elemental Analyzer (model 240)." The amount of protein contained in each sample was then determined by multiplying this value by 6.25. It was found that the amount of fat plus ash determined by the methods described earlier, along with the amount of protein calculated by this method, accounted for an average of 95% of the dry weight of these samples.

Data Compilation and Analysis

Data on weight and length were taken every 10 days, and mortality in each experimental tank was recorded daily. The weight and length of all fish remaining at the end of the experiment were measured on July 18. Growth was depicted as a linear relationship by plotting the $\log_{10}$ of weight against time. The slopes for the graphs showing changes in weight, and body fat under different experimental conditions were obtained by regression analysis. The condition factor (100) W/L^3 (Brown, 1957), where W = weight and L = length, and the coefficient of variability (amount of variability independent of the mean) were also used to compare the various treatments.

<u>Method for Determining Maximum Consumption and Digestion Rate (Gastro-Intestinal Motility)</u>

In two experiments involving two different temperatures (13.5 and 16.5 C) and two different dissolved oxygen concentrations (6.2 and 8.4 ppm), the maximum food consumption and digestive rate were compared between fish fed the two diets.

The first experiment involved a temperature of 13.5 C and a dissolved oxygen concentration of 6.2 ppm. A total of 25 fish (average weight 14.1 g) were fed Ewos and an equal number (average weight 17.2 g) were fed Oregon moist. The fish used in the experiment were fed the same diet they had been raised on, and up until the experiment were held at 17 ± 0.5 C. This experiment lasted for 8 hrs with five fish being removed initially and every 2 hrs thereafter for each of the diets tested.

The second experiment involved a temperature of 16.5 C and a dissolved oxygen concentration of 8.4 ppm. A total of 50 fish (average weight 15.8 g) were fed Ewos, and an equal number (average weight 17.7 g) were fed Oregon moist. These fish had originally been raised at 14 ± 0.5 C and were also fed the same diet they had been raised on. In this experiment 5 fish were removed initially from each of the two tanks and 5 fish at 1.5, 2.5, 3.5, 4.5, 6.5, 8.5, 10.5, and 12.5 hr intervals in an attempt to get an accurate estimate of the rate of digestion.

Fish for both experiments were starved for 48 hrs prior to the test to empty the stomach and intestine of food, then fed in excess for 1 hr. This was believed to be enough time to satiate the fish since Brett (1971) found when food was presented in excess at 15 C to sockeye salmon, mean satiation time was found to be 43 ± 8 min, independent of fish size.

The amount of food in the stomach and intestine initially and at each time interval, was measured. Fish were killed by placing them in a dilute concentration of MS 222 (100 ppm). Higher concentrations of MS 222 caused regurgitation. The fish were blotted dry and weighed to the nearest 0.01 g. The stomach and intestine were removed by clamping the esophagus with a pair of forceps, opening the abdominal cavity, cutting the intestine at the anus and the esophagus above the forceps. The stomach and intestine were separated at the pylorus. The stomach contents were removed by stripping into a tared aluminum pan. The intestinal remains also were stripped into tared pans. The transparency of the intestine indicated complete removal. The stomach and faecal material were dried to a constant weight (105 C for 12 hrs) and weighed to 0.1 mg.

In both experiments there was a problem with fish regurgitating food, especially in the first few sampling periods. This caused problems since it was very difficult to remove regurgitated food from between the gill filaments. Those fish consuming the most food, as indicated by distention of the body, seemed to be most likely to regurgitate. In the first experiment all fish autopsied were used to calculate results, regardless of whether they regurgitated. Undoubtedly this biased results since much of the regurgitated food was not recovered. In the second experiment those fish regurgitating in excess were discarded, this too caused bias since it was usually the fish consuming the most food that were most likely to regurgitate.

The size range of the fish fed the Oregon moist diet were larger than Ewos fed fish in both experiments, and this is considered in the results.

The mean amount of food in the stomach or intestine (dry weight) as a percent of total body weight (wet weight) for a given time period was determined by calculating a value for each fish, and then taking the average value for all the fish tested during that time period.

RESULTS AND DISCUSSION

Mortality

Mortality in the first 10 days was extremely high for all groups of fish, but was much reduced during the remaining period of the experiment (Tables 1 and 2). Mortality was greatest for fish fed the dry diet at all three temperatures tested, and was especially high for fish raised at 12 C (Table 2). It was noted that most of the fish that died had not started to feed.

A measure of the coefficient of variability for the length data indicates a high proportion of these non-feeding fish in the tanks fed the dry diet (Table 3). The greater variability of the length data in the dry diet groups, especially the two warmest temperatures, is probably contributed from these non-feeding fry.

Since metabolic rate increases with temperature it would be assumed that these non-feeding fish would die first at the warmest temperature and last at the coldest. This indeed seems to be the case. The largest die-off occurred between 30-40 days at a temperature of 17 C while the large die-off at 12 C did not occur until 60-70 days after the experiment began (Table 1).

Table 1. Mortality during each 10 day time period from an initial stock of 650 fish

	Oregon Moist			Ewos		
Days	17 C	14 C	12 C	17 C	14 C	12 C
0-10	150	136	156	128	152	187
11-20	2	2	4	5	7	2
21-30	0	2	2	1	0	1
31-40	1	2	0	6	2	0
41-50	0	0	0	1	2	1
51-60	2	0	0	2	5	3
61-70	0	1	0	0	3	29
71-80	1	2	0	0	0	2
81-90	0	0	0	0	1	3
91-100	0	1	0	0	0	0
101-110	0	0	0	0	0	0
111-120	0	0	0	0	0	1
121-130	0	0	0	0	0	0
131-140	0	0	0	0	0	0
141-150	0	0	0	0	0	2
151-160	0	0	0	1	0	0

Table 2. Percent initial mortality (first 10 days of experiment) and percent mortality thereafter

	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
Initial Mortality:						
Percent dying	23.1	20.9	24.0	19.7	23.4	28.8
Number dying	150	136	156	128	152	187
Mortality After First 10 Days of Experiment (Total of 150 Days):						
Percent dying	1.2	1.9	1.2	3.1	4.0	9.5
Number dying	6	10	6	16	20	44

Table 3. Coefficient of variability (amount of variability independent of mean) for average length of 20 fish sampled from each of the rearing tanks every 10 days

Sampling Date	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
Feb. 7	0.05	0.05	0.05	0.05	0.05	0.05
17						
27	0.08	0.10	0.07	0.11	0.10	0.09
March 9	0.11	0.12	0.11	0.17	0.15	0.12
19	0.09	0.12	0.13	0.16	0.16	0.13
29	0.13	0.14	0.09	0.15	0.19	0.15
April 8	0.11	0.09	0.09	0.17	0.15	0.11
18	0.08	0.06	0.12	0.15	0.17	0.11
28	0.07	0.11	0.12	0.16	0.12	0.10
May 8	0.10	0.11	0.12	0.15	0.13	0.12
18	0.08	0.09	0.10	0.06	0.10	0.17
28	0.09	0.11	0.10	0.07	0.09	0.14
June 7	0.11	0.12	0.11	0.06	0.11	0.12
17	0.11	0.09	0.08	0.08	0.10	0.13
27	0.07	0.10	0.12	0.08	0.11	0.16
July 7	0.08	0.10	0.11	0.08	0.10	0.13
17	0.09	0.08	0.12	0.07	0.10	0.07
18 (Final)	0.08	0.10	0.11	0.08	0.10	0.08

A well known disadvantage of pelleted diets is the reluctance of fish to initially start feeding on them. Oregon moist does not seem to cause this problem, while Ewos does. Locke and Linscott (1969) compared the effect of feeding Ewos vs. 100% beef liver on the growth of lake trout and Atlantic salmon. They found that mortality in both lake trout and salmon was greatest (9.5%) when fed Ewos compared to beef liver (6.2%). It was also noted that the greatest mortality occurred in the hatchery with the coldest water supply.

Mortality, other than that apparently related to non-feeding, was extremely low for both diets. Thus it appears that both diets were nutritionally adequate, once the fish had started feeding.

Body Composition

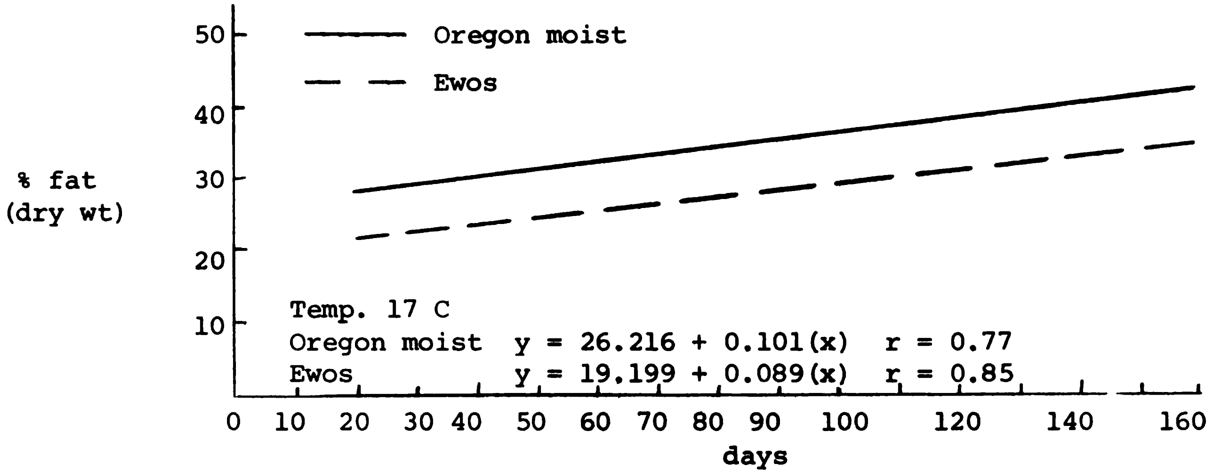
Fat: The most variable body component was fat. The percentage of fat (Table 4) was greatest for fish fed the moist diet regardless of temperature. The highest fat content was in fish fed Oregon moist and reared at 17 C, reaching a high of 42.8% of dry weight at the end of the experiment. The fat content in all fish (regardless of diet) increased as temperature increased (Fig. 1).

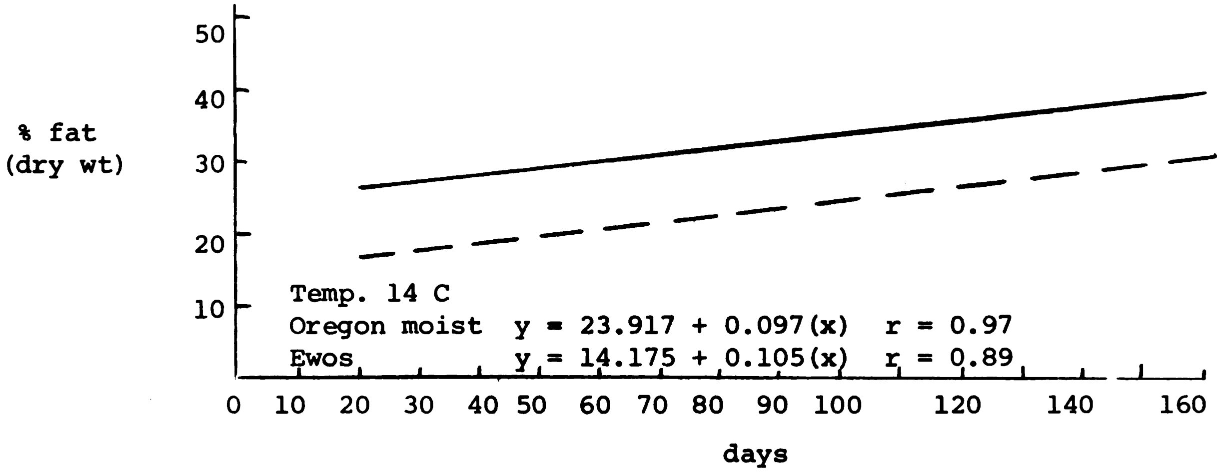
The amount of fat in fish fed Ewos or Oregon moist increased over time at approximately the same rate except at the coldest temperature tested (Fig. 1). This is believed

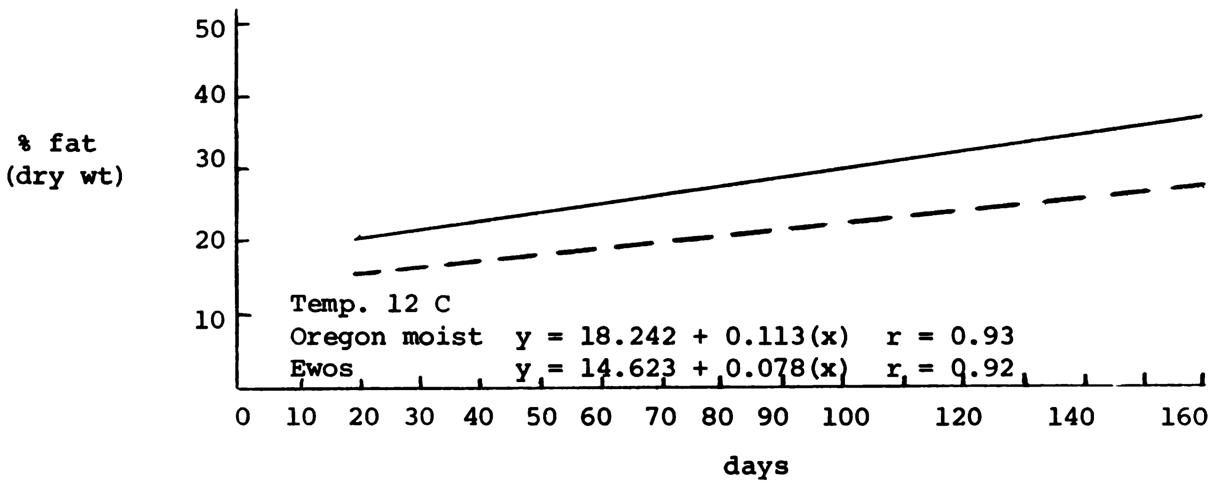
Table 4. Percent fat (dry weight) based on a subsample from 20 fish sampled every 10 days from each of the rearing tanks

Sampling Date		Oregon Moist			Ewos	
	17 C	14 C	12 C	17 C	14 C	12 C
Feb. 7	16.0	16.0	16.0	16.0	16.0	16.0
17						
27	34.0	26.3	21.4	17.1	17.9	17.7
March 9	17.5	27.3	15.6	29.0	10.8	20.2
19	33.5	25.6	24.1	19.5	19.4	16.4
29	33.0	31.2	26.0	23.6	22.2	17.5
April 8	32.2	30.0	26.3	24.4	21.8	17.1
18	33.8	28.7	25.2	25.5	23.1	20.5
28	33.8	30.8	28.0	25.2	20.4	19.4
May 8	37.2	33.7	29.9	27.6	23.8	21.7
18	36.6	33.9	30.0	28.3	26.0	21.5
28	37.6	34.8	31.9	29.8	27.2	22.1
June 7	38.5	36.2	32.0	30.6	23.0	24.0
17	37.9	36.5	31.1	30.3	29.4	26.0
27	40.4	36.3	33.8	30.3	28.9	25.2
July 7	40.3	38.9	34.4	33.6	29.6	26.2
17	42.8	39.7	35.8	32.7	30.2	28.8

Figure 1. Rate of fat increase from 20 days after initial feeding until the termination of the experiment (data based on 15 sampling periods).


Oregon moist
Ewos
% fat (dry wt)
50
40
30
20
10
Temp. 17 C
Oregon moist y = 26.216 + 0.101(x) r = 0.77
Ewos y = 19.199 + 0.089(x) r = 0.85
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days


% fat (dry wt)
50
40
30
20
10
Temp. 14 C
Oregon moist y = 23.917 + 0.097(x) r = 0.97
Ewos y = 14.175 + 0.105(x) r = 0.89
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days


% fat (dry wt)
50
40
30
20
10
Temp. 12 C
Oregon moist y = 18.242 + 0.113(x) r = 0.93
Ewos y = 14.623 + 0.078(x) r = 0.92
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days

to be due to the high number of non-feeding fish in the tank fed Ewos at a temperature of 12 C. These fish became part of the sample analyzed for fat and tended to reduce the percentage of fat in these samples early in the experiment. The data for the first 20 days of the experiment was excluded from analysis because of the variability due to non-feeding fish.

It was assumed that by day 20 all the fish that were going to feed had started. Figure 2 shows the effect of temperature and diet on fat accumulation in the first 20 days of the experiment. In the first 20 days of the experiment fish fed Oregon moist at all temperatures accumulated more fat than fish fed Ewos at the same temperature. Also, the greater the temperature the greater the increase in fat for fish fed Oregon moist. Fish fed Ewos acquired very little fat in the first 20 days of the experiment, regardless of temperature. Thus it appears that in the first 20 days of the experiment the fish fed Oregon moist obtain a higher percentage of body fat than fish fed Ewos (Fig. 2), and they retain this higher percentage of body fat throughout the experiment, though the rate of fat increase from this time on is approximately equal for all fish, regardless of diet (Fig. 1). Vanstone and Market (1968) working with coho salmon, Parker and Vanstone (1966) with pink salmon, and Groves (1970) with sockeye salmon also found that fat tends to increase with body size, but is much more

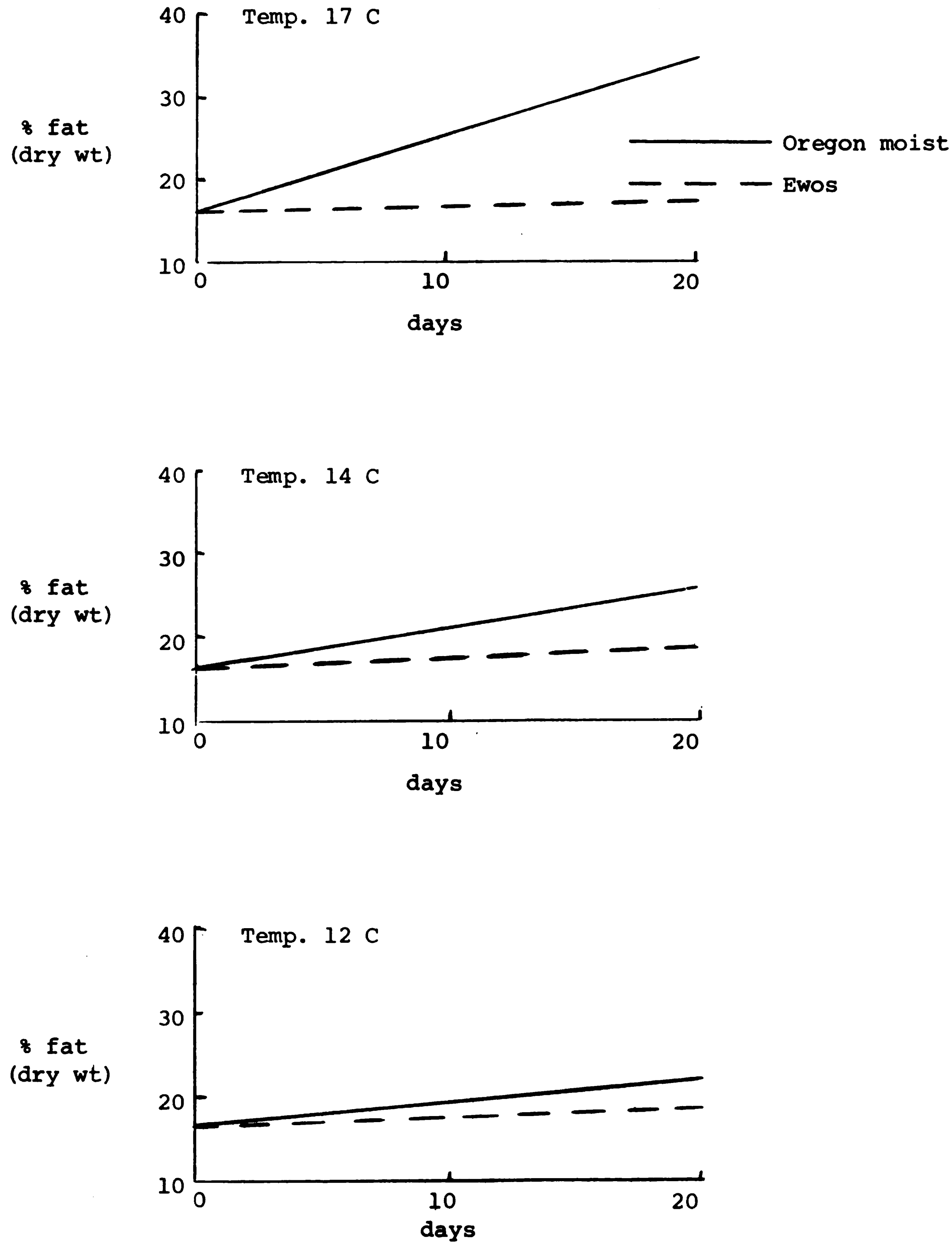


Figure 2. Rate of fat increase for the first 20 days of the experiment (data based on 2 sampling periods).

closely a function of the previous nutritional history of the fish.

Groves' (1970) data and that of Parker and Vanstone (1966) suggest that in the growth of sexually immature salmon, the primary variable in determining condition is body fat. The fat-free mass (protein plus ash) of sockeye was shown to be a function of fork length. Differences between predicted fat-free mass and the actual body weight at any given length represent differences in the amount of body fat, which in turn reflects the adequacy or inadequacy of the nutritional environment.

In salmonids "fatness" is usually estimated as the "condition factor," which is the ratio between the observed weight and length cubed, times 100. The condition factor (K) was compared between fish fed Ewos and fish fed Oregon moist at the three temperatures tested. Fish that were 10, 11, and 12 cm long were used and their average weight computed (Table 5). Fish fed Oregon moist had a higher K value than fish fed Ewos at all temperatures tested, except for 11 cm fish at 12 C, in which case the Ewos fed fish had a slightly higher K value. The difference in condition factors was greatest at 17 C, where differences in percent fat for a given test period were also greatest (Table 4). Thus it appears that fish fed Oregon moist were better able to accumulate fat than fish of equal size fed Ewos.

Table 5. Condition factors (K) for fish raised at the three different temperatures and fed the two different diets (data based on fish remaining at the end of the experiment)

	Size of Fish					
Sample Groups	10 cm	n	11 cm	n	12 cm	n
Temperature 17 C						
K (Oregon moist)	1.046 ± 0.016	2	1.031 ± 0.022	6	1.045 ± 0.024	6
K (Ewos)	0.874 ± 0.007	2	0.953 ± 0.031	8	0.940 ± 0.022	7
Temperature 14 C						
K (Oregon moist)	0.988	1	0.981 ± 0.022	9	1.033 ± 0.023	9
K (Ewos)	0.922 ± 0.025	4	0.942 ± 0.021	9	1.019 ± 0.018	12
Temperature 12 C						
K (Oregon moist)	0.943 ± 0.020	4	0.971 ± 0.015	7	1.050 ± 0.021	4
K (Ewos)	0.913 ± 0.034	5	0.994 ± 0.021	9	0.990 ± 0.017	5

Values are means ± standard error.

Water: In any given sample when percent fat is high, the percent water is low (Table 6). This agrees with Love (1970), who states that water content is usually inversely related to the lipid content in the muscle of fatty fish.

Ash: The percent ash content (Table 7) also shows an inverse relationship with fat. The percent ash content was lower for fish fed Oregon moist than those fed Ewos at any given temperature. This reflects the higher percentage of fat in fish fed Oregon moist (Table 4). The relationship between fish fed the same diet at different temperatures, and the ash content, is not so pronounced. This may in part be due to the small amount of ash in the samples tested. Because of the small sample size the ash content was the most variable component measured. The percent fat and ash in the samples appeared to be more dependent on the type of diet fed than on rearing temperature.

Protein: Protein (Table 8) was only measured for samples taken on July 17 at the conclusion of the experiment. The percentage of protein was higher in fish fed Ewos at all temperatures, when compared to those fed Oregon moist. This is due to the lower percentage of fat in fish fed Ewos.

Phillips et al. (1963), working with brook and lake trout, has shown that the sum of the protein and ash may change according to the lipid content, but the proportion of the two do not vary. He found the dry lipid-free residue

Table 6. Percent water (wet weight) based on a subsample from 20 fish sampled every 10 days from each of the rearing tanks

Sampling Date	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
Feb. 7	78.4	78.4	78.4	78.4	78.4	78.4
17						
27	78.2	78.6	79.8	80.4	79.4	80.3
March 9	77.2	78.0	78.4	78.8	78.7	79.5
19	75.6	76.6	77.9	78.4	79.0	79.5
29	75.2	75.8	78.0	76.9	77.5	79.6
April 8	74.3	75.6	77.4	76.6	76.8	79.0
18	73.5	76.3	78.1	75.6	77.2	80.9
28	73.6	75.0	76.5	75.8	76.6	77.6
May 8	73.3	73.6	75.2	74.4	75.8	78.1
18	72.8	73.5	75.0	73.6	74.7	77.2
28	71.6	72.9	74.9	73.0	74.3	76.5
June 7	70.7	72.6	73.8	73.5	74.2	75.6
17	71.5	71.6	74.0	72.8	73.4	75.6
27	70.0	71.0	72.2	72.4	72.8	74.3
July 7	70.5	70.7	72.2	71.5	73.1	74.0
17	67.6	70.2	71.8	71.2	72.4	73.2

Table 7. Percent ash (dry weight) based on a subsample from 20 fish sampled every 10 days from each of the rearing tanks

Sampling Date	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
Feb. 7	5.8	5.8	5.8	5.8	5.8	5.8
17						
27	10.1	9.0	9.8	11.7	10.7	10.9
March 9	9.9	9.7	10.6	12.6	10.6	9.7
19	9.7	9.3	9.4	12.0	11.2	9.2
29	9.9	9.3	9.2	10.0	10.5	8.9
April 8	9.7	10.2	9.6	10.0	10.4	10.3
18	8.4	9.8	9.7	10.5	8.8	9.2
28	8.7	8.7	8.4	10.3	10.3	10.6
May 8	8.8	8.7	8.4	9.5	9.4	9.7
18	8.1	8.2	8.0	9.3	8.4	10.3
28	8.1	8.5	8.4	9.8	9.2	10.0
June 7	9.1	9.1	8.2	9.4	9.3	10.2
17	8.3	8.4	8.5	9.0	9.6	9.3
27	8.1	7.5	7.9	9.1	9.2	8.8
July 7	7.4	7.5	8.2	9.6	9.2	8.7
17	8.2	7.3	8.2	8.6	8.4	8.4

Table 8. Percent protein (dry weight) for samples taken on July 17

	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
July 17	48.6	49.4	49.1	52.3	54.6	54.2

consisted of 86.5% protein and 13.5% ash, no matter what the water and lipid contents had been. In the present study both protein and ash content showed only slight differences between fish fed the same diet but reared at different temperatures (Table 7 and 8).

Growth

Beginning with the first sample taken after 20 days and throughout the experimental period the fish fed Oregon moist were larger (weight and length) than fish fed Ewos at all temperatures tested. Throughout most of the experiment the difference was most pronounced at the coldest temperature (Tables 9 and 10). The rates of growth (Fig. 3) were determined by plotting the $\log_{10}$ of weight against time. A linear relationship existed for the first 80 days at a temperature of 17 C, regardless of diet, and at 14 C the linear relationship existed for 100 days. At a temperature of 12 C growth rate was linear for 120 days when fish were fed Oregon moist, but the growth rate of fish fed Ewos maintained a linear relationship throughout the total experiment of 160 days. Because of this variability in the rate of growth with temperature and diet, the rate of growth for fish at 17 C was determined from weight data taken during the first 80 days of the experiment, and the rate of growth for fish kept at 14 C and 12 C was determined by weight data taken during the first 100 days of the experiment (Fig. 3).

Table 9. Average weight of 20 fish taken each 10 day sampling period and average weight of fish remaining at the end of the experiment (grams)

Sampling Date	Oregon Moist			Ewos		
	17 C	14 C	12 C	17 C	14 C	12 C
Feb. 7[a]	0.36	0.36	0.36	0.36	0.36	0.36
27	0.72	0.67	0.54	0.62	0.65	0.49
March 9	1.04	0.89	0.83	0.98	0.86	0.71
19	1.59	1.12	1.25	1.32	1.03	0.94
29	1.96	1.85	1.18	2.08	1.58	1.16
April 8[a]	2.54	2.29	1.65	2.30	2.16	1.29
18	4.07 ± 0.21	3.32 ± 0.15	2.73 ± 0.20	3.33 ± 0.30	3.19 ± 0.31	1.56 ± 0.16
28	5.48 ± 0.26	5.06 ± 0.36	3.87 ± 0.36	4.49 ± 0.40	3.63 ± 0.32	2.12 ± 0.18
May 8	5.35 ± 0.38	5.90 ± 0.45	4.16 ± 0.33	5.29 ± 0.43	5.16 ± 0.45	2.79 ± 0.29
18	7.00 ± 0.35	7.27 ± 0.48	5.78 ± 0.40	6.50 ± 0.27	7.63 ± 0.51	4.10 ± 0.51
28	7.62 ± 0.51	8.19 ± 0.63	7.30 ± 0.52	7.60 ± 0.38	8.71 ± 0.61	4.12 ± 0.39
June 7	8.81 ± 0.64	9.32 ± 0.83	10.14 ± 0.82	8.80 ± 0.34	9.88 ± 0.82	6.92 ± 0.59
17	10.81 ± 0.81	10.56 ± 0.73	9.99 ± 0.52	9.70 ± 0.56	10.88 ± 0.84	7.86 ± 0.73
27	13.82 ± 0.79	12.84 ± 0.85	10.51 ± 0.91	10.58 ± 0.63	11.52 ± 0.95	9.28 ± 0.84
July 7	13.15 ± 0.84	15.20 ± 1.02	11.56 ± 1.10	13.40 ± 0.85	12.65 ± 0.88	10.89 ± 1.01
17	18.15 ± 1.14	18.23 ± 1.11	13.51 ± 1.19	15.13 ± 0.79	13.97 ± 1.07	15.62 ± 0.85
18	17.21 ± 0.33[b]	17.71 ± 0.40[c]	14.18 ± 0.36[d]	14.20 ± 0.31[b]	15.85 ± 0.37[c]	13.57 ± 0.30[d]
	n = 206[e]	n = 216[e]	n = 190[e]	n = 152[e]	n = 193[e]	n = 120[e]

[a]Standard error of the mean for samples taken Feb. 7th thru April 8th are unavailable due to loss of data.

[b]Significantly different at the 0.001 α level from t-test.

[c]Significantly different at the 0.001 α level from t-test.

[d]Significantly different at the 0.04 α level from t-test.

[e]n equals number of fish remaining at end of experiment (April 18) from which final average weight was determined.

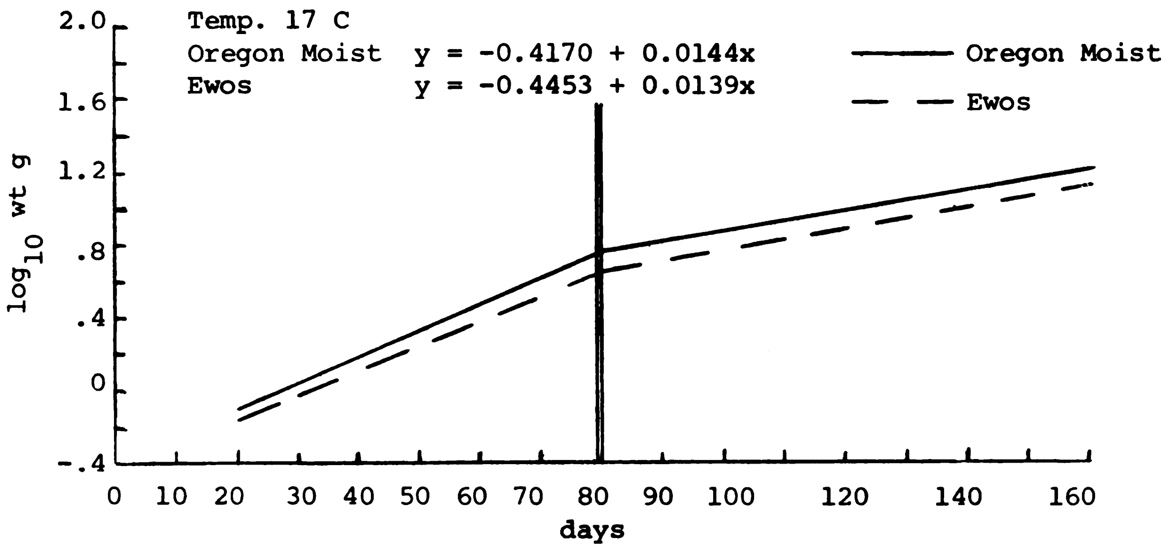
Table 10. Average length of 20 fish taken each 10 day sampling period and average length of fish remaining at the end of the experiment (cm)[a]

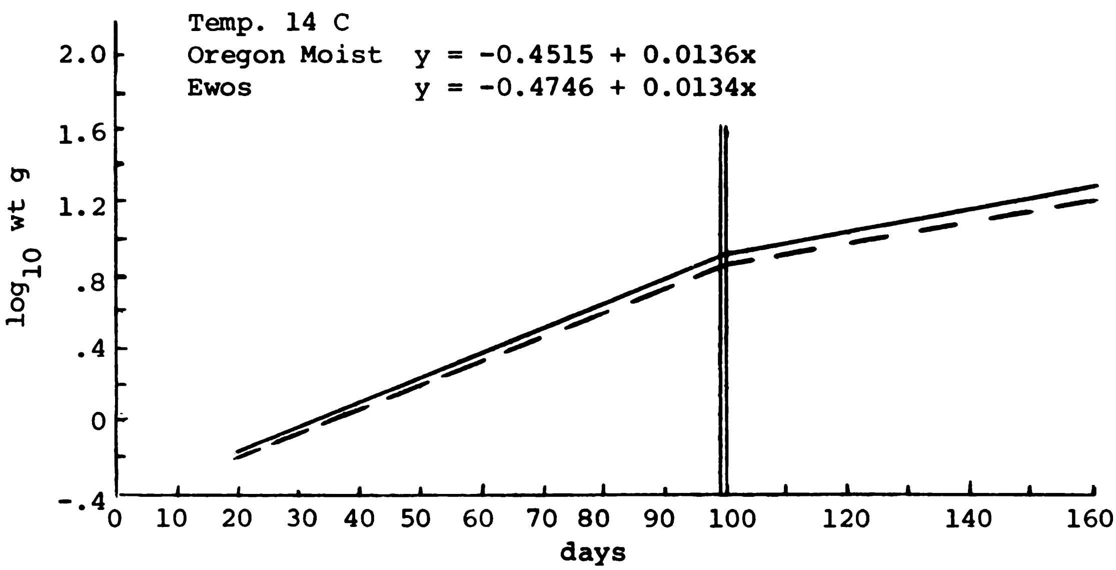
Sampling Date		Oregon Moist 17 C	Oregon Moist 14 C	Oregon Moist 12 C	Ewos 17 C	Ewos 14 C	Ewos 12 C
Feb.	7	3.2 ± 0.03	3.2 ± 0.03	3.2 ± 0.03	3.2 ± 0.03	3.2 ± 0.03	3.2 ± 0.03
	17						
	27	3.8 ± 0.07	3.9 ± 0.09	3.7 ± 0.06	3.8 ± 0.09	3.9 ± 0.08	3.6 ± 0.07
March	9	4.3 ± 0.10	4.2 ± 0.11	4.2 ± 0.10	4.3 ± 0.16	4.2 ± 0.14	4.2 ± 0.11
	19	5.0 ± 0.10	4.6 ± 0.12	4.7 ± 0.14	4.7 ± 0.17	4.4 ± 0.16	4.3 ± 0.12
	29	5.4 ± 0.15	5.3 ± 0.17	4.7 ± 0.09	5.3 ± 0.18	4.9 ± 0.21	4.5 ± 0.15
April	8	6.0 ± 0.14	5.9 ± 0.12	5.1 ± 0.10	5.7 ± 0.22	5.7 ± 0.19	4.9 ± 0.12
	18	6.8 ± 0.12	6.4 ± 0.09	6.0 ± 0.16	6.2 ± 0.22	6.2 ± 0.24	5.4 ± 0.14
	28	8.0 ± 0.12	7.8 ± 0.19	7.2 ± 0.20	7.3 ± 0.27	7.0 ± 0.19	6.2 ± 0.14
May	8	8.0 ± 0.18	8.3 ± 0.20	7.6 ± 0.21	8.0 ± 0.26	7.9 ± 0.23	6.6 ± 0.18
	18	8.7 ± 0.15	8.8 ± 0.18	8.4 ± 0.18	8.7 ± 0.11	9.1 ± 0.19	7.3 ± 0.28
	28	9.1 ± 0.19	9.3 ± 0.23	9.1 ± 0.21	9.2 ± 0.15	9.5 ± 0.19	7.6 ± 0.23
June	7	9.5 ± 0.24	9.5 ± 0.25	9.7 ± 0.25	9.5 ± 0.13	9.8 ± 0.25	8.6 ± 0.23
	17	10.0 ± 0.25	10.1 ± 0.20	10.0 ± 0.17	9.9 ± 0.19	10.2 ± 0.23	9.1 ± 0.27
	27	11.0 ± 0.17	10.8 ± 0.24	10.1 ± 0.27	10.2 ± 0.18	10.5 ± 0.26	9.6 ± 0.34
July	7	10.6 ± 0.20	11.3 ± 0.25	10.4 ± 0.26	10.9 ± 0.20	10.7 ± 0.24	10.1 ± 0.29
	17	11.8 ± 0.25	11.9 ± 0.21	10.8 ± 0.30	11.5 ± 0.19	11.0 ± 0.25	11.5 ± 0.19
	18	11.67 ± 0.07	11.82 ± 0.08	11.10 ± 0.09	11.35 ± 0.07	11.59 ± 0.08	11.06 ± 0.08
		n = 206[b]	n = 216[b]	n = 190[b]	n = 152[b]	n = 193[b]	n = 120[b]

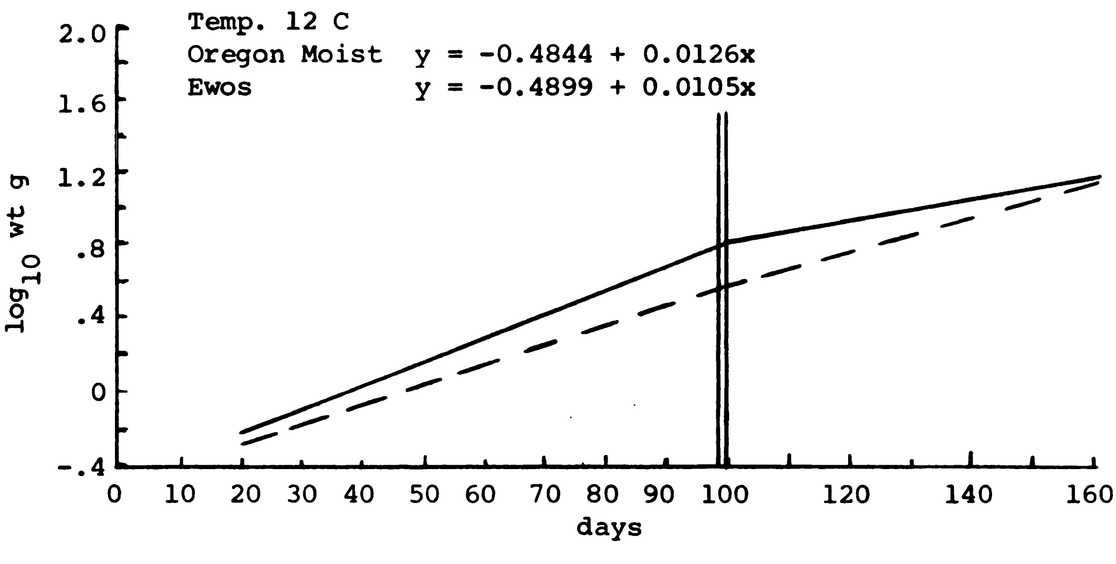
[a]The small difference between final average lengths for fish raised at the same temperature but fed different diets are not significantly different statistically.

[b]n equals number of fish remaining at end of experiment (July 18) from which final average weight was determined.

Figure 3. Rate of growth (weight) from 20 days after feeding until the termination of the experiment (total of 140 days).


Temp. 17 C
Oregon Moist y = -0.4170 + 0.0144x
Ewos y = -0.4453 + 0.0139x
Oregon Moist
Ewos
log10 wt g
2.0
1.6
1.2
.8
.4
0
-.4
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days


Temp. 14 C
Oregon Moist y = -0.4515 + 0.0136x
Ewos y = -0.4746 + 0.0134x
log10 wt g
2.0
1.6
1.2
.8
.4
0
-.4
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days


Temp. 12 C
Oregon Moist y = -0.4844 + 0.0126x
Ewos y = -0.4899 + 0.0105x
log10 wt g
2.0
1.6
1.2
.8
.4
0
-.4
0 10 20 30 40 50 60 70 80 90 100 120 140 160
days

The growth rate from the time the data became non-linear until the end of the experiment was determined by drawing a line from the average weight at the beginning of non-linear growth to the average weight of fish at the end of the experiment. The average weight of fish at the end of the experiment was based on the remaining fish (Table 9).

In Figure 3 the first 20 days of the experiment are not considered in determining growth rate, since during this period not all fish were feeding and the effect of the diet on growth would not be in effect. Theoretically the time that a specific fish of a given cohort will start to feed is genetically variable, distributed normally around some mean. Thus the fish kept at equal temperatures, but fed different diets should all be feeding at approximately the same time, if diet has no effect on this variable. The growth rate in the first 20 days of the experiment for fish kept at equal temperatures but fed different diets would be a reflection of how well the fish start to feed on the diet and the nutritional value of the diet. Figure 4 shows the rate of growth from the time that 50% of the fish started to feed (determined from visual observation), until 20 days after. It appears that the rate of growth during the first 20 days of the experiment was greater for fish fed Oregon moist than for fish fed Ewos, indicating that Oregon moist is either utilized more efficiently for growth or it is accepted more readily. It has already been shown that lipid

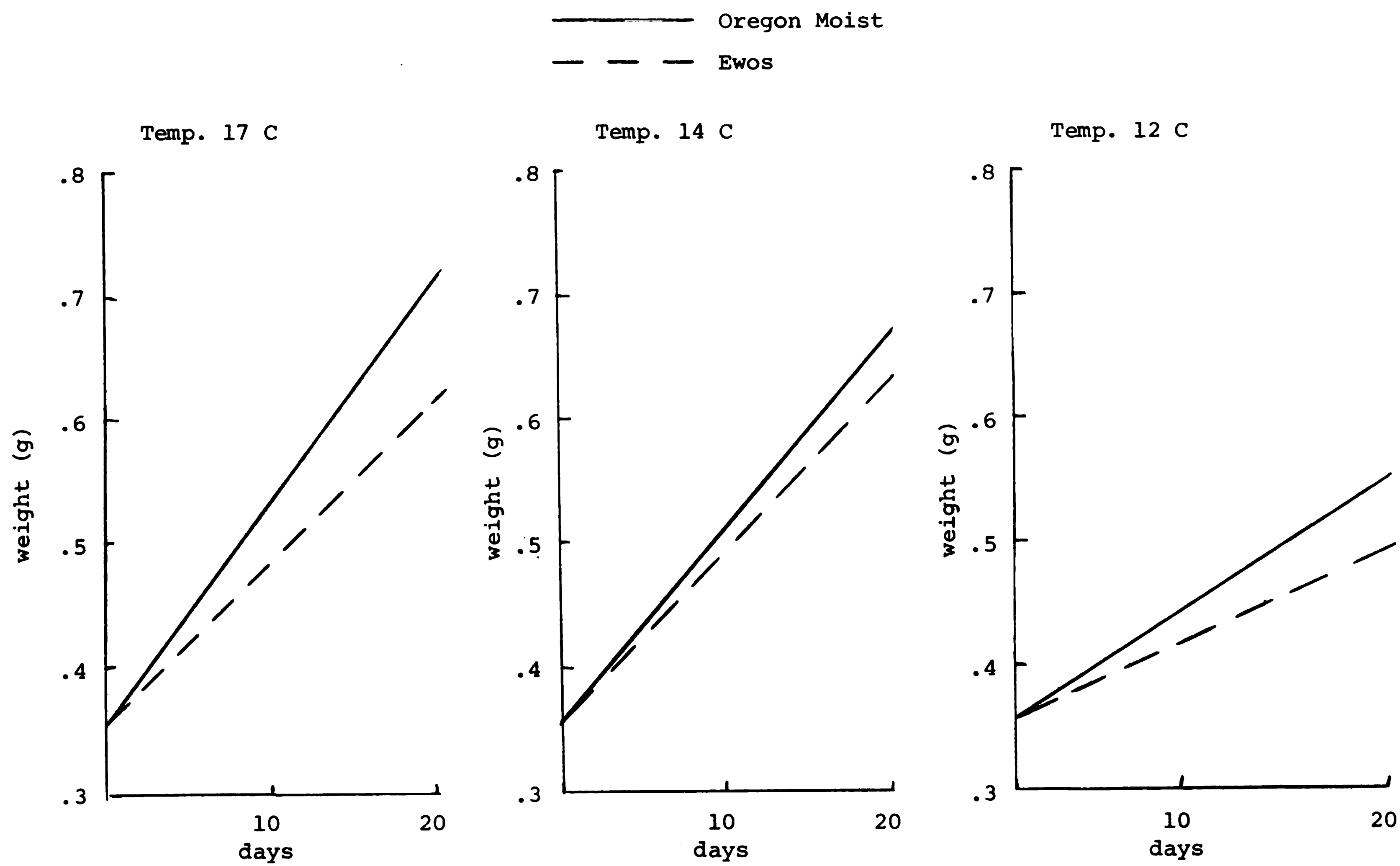


Figure 4. Rate of growth (weight) for the first 20 days of experiment.

content increases most rapidly in fish fed Oregon moist (Fig. 2), and the increase is greatest with increasing temperature. This same trend is seen in the initial growth rate. The increase in growth is greatest for fish fed Oregon moist and increases with increasing temperature. It appears that growth rate for fish fed Ewos is approximately the same, regardless of temperature, which is also the case for lipid increase in Ewos fed fish. However, the fish fed Ewos and reared at 12 C have an initial growth rate somewhat lower than fish fed Ewos and reared at warmer temperatures. This is believed to be due to the high number of non-feeding fish in this tank that would be losing weight.

At any test period the fish fed Oregon moist were larger than fish fed Ewos, and this reflects the higher fat content in all fish fed Oregon moist (Fig. 1). The difference in weight between fish fed different diets, and raised at the same temperature is approximately equal, except at 12 C. At this temperature the rate of growth for fish fed Ewos in the first 100 days is approximately equal to the rate of growth thereafter, thus the weight of fish fed Ewos first decreases then increases in comparison to the weight of fish fed Oregon moist (Fig. 3). The large number of non-feeding fish in the Ewos group at 12 C probably contributed to the lower growth rate observed in this group. If these non-feeding fish had not been included in the samples then the rate of growth for the first 100 days would have nearly equalled those of the Oregon moist group.

The growth rate varied with temperature and age of fish. During the first 80 days the growth of fish at 17 C, regardless of diet, was the greatest, but from this time on fish reared at 14 C grew the fastest (Fig. 3 and Tables 9 and 10). Thus the average size of fish at the end of the experiment were largest for fish raised at 14 C. Brett et al. (1969) also saw this differential rate of growth in sockeye when they were raised at different temperatures and fed excess diet. He found that fish raised at 20 C grew fastest during the first 20-30 days of growth when compared to fish raised at 10 C or 15 C. After 20-30 days the fish kept at 15 C grew the fastest. The fish raised at 10 C showed the most steady rate of increase and after approximately 200 days the fish kept at 15 C were the largest and the fish kept at 10 C and 20 C were approximately the same size.

Thus it appears that the optimum temperature for growth of sockeye and coho, when fed excess ration, decreases as fish size increases. Brett et al. (1969) found that when sockeye were fed excess ration the 5-7 months old fish grew best at 15 C, but when the fish were 7-12 months old they grew better at 10 C than they did at 15 C.

It was noted earlier that regardless of diet, fish kept at 17 C accumulated the highest percentage of lipid (Table 4). This is probably a reflection of the greater food consumption with increasing temperature. Averett (1969), found that when food was not limiting, consumption increased with increasing temperature from 5-17 C in coho salmon. Brett and Higgs (1970) working with sockeye found that food consumption was greater at 20 C than at 15 C or 10 C. Since the amount of food consumed in proportion to total body weight decreases with increasing fish size (Brett, 1971), the increase in food consumption and thus higher percent of body fat during initial growth should be most pronounced at the warmest temperature. Thus the more rapid rate of growth during the first 80 days for fish kept at 17 C in comparison to fish kept at lower temperatures is most likely a reflection of the high food consumption rate, producing a high percentage of body fat. As the fish get larger food consumption and growth decrease, thus the fish reared at 17 C would show a decrease in growth first in comparison to fish reared at colder temperatures. After 160 days the fish held at 14 C showed the largest overall size. Even though their initial growth was less than the fish at 17 C, their growth after 80 days was significantly greater than the fish at 17 C. It is believed that if the trends of growth exemplified in the first 160 days were allowed to continue, eventually the fish at 12 C would be the largest.

The experiment was terminated because it was believed that the fish were showing definite signs of smolting (silvering and loss of parr marks). Temperature or diet did not seem to effect the number of fish smolting. When the remaining fish were examined at the end of the experiment only about 10% did not show signs of smoltification, and these tended to be the smaller fish for each treatment. Only one fish had lost all parr marks and appeared to have completed smoltification. This fish weighed 37.22 grams and was 15.7 cm long.

Under artificial rearing conditions a decrease in lipids with parr-smolt transformation has been observed in many species of salmon, including coho (Groves, 1970, Vanstone and Market, 1968; Parker and Vanstone, 1966; Hoar, 1939; and Lovern, 1934). Only in the fish fed Ewos and reared at 17 C did there appear to be any loss in lipid (Table 4). The fact that lipid did not decrease in the other tanks may be an indication that smoltification had not progressed very far by the termination of the experiment. Vanstone and Market (1968) observed that a decrease in lipid during smoltification in wild coho did not occur. Groves (1970) feels that transformation may result from growth in length and lean mass at the expense of stored fat in a nutritional environment where energy is limiting. If the diet of the fish during this period was adequate with respect to both protein and energy then no loss of lipid may occur. The fact that lipid content of fish did not decrease during the period when my experimental fish were believed to be smolting, may be an indication that both diets are adequate with respect to both protein and energy.

Maximum Food Consumption and Digestion Rate

The amount of food consumed, which is related to the capacity of the stomach and the rate of digestion (gastro-intestinal motility), is a prime factor limiting growth (Brown, 1957). The two diets were thus tested, to measure their effect on this variable. At a temperature of 13.5 C and 16 .5 C, when fish were fed to satiation, the fish fed Oregon moist consumed more than fish fed Ewos (Table 11). The rate of digestion was also greatest for fish that had consumed Oregon moist in comparison to fish fed Ewos at both temperatures (Figs. 5 and 6). In conjunction with the greater consumption and digestion rate for fish fed Oregon moist, the amount of material in the intestine and rate of filling of the intestine was also greater for fish fed Oregon moist at both temperatures tested (Table 11).

If one assumes that food consumption is a function of activity, which is a function of temperature, food consumption can be expected to increase to some maximum and

Table 11. Average amount of food consumed (dry weight) at satiation in proportion to fish wet weight and proportion of food remaining in the stomach and intestine at different time intervals after satiation[a] (Experiment A: Temperature = 13.5 C, DO = 6.2 ppm, mean wt of fish fed Oregon moist = 21.58 g, Ewos = 16.12 g; Experiment B: Temperature = 16.5 C, DO = 8.4 ppm, mean wt of fish fed Oregon moist = 23.08 g, Ewos = 18.14 g)

	Time Intervals				
Diet	Satiation	2 hrs	4 hrs	6 hrs	8 hrs
Experiment A[b]					
			Stomach		
Oregon moist	0.705 ± 0.15	0.487 ± 0.09	0.319 ± 0.06	0.354 ± 0.09	0.278 ± 0.02
Ewos	0.511 ± 0.10	0.260 ± 0.05	0.322 ± 0.11	0.350 ± 0.08	0.318 ± 0.05
			Intestine		
Oregon moist	0.056 ± 0.00	0.083 ± 0.01	0.130 ± 0.02	0.227 ± 0.01	0.260 ± 0.05
Ewos	0.040 ± 0.01	0.101 ± 0.01	0.111 ± 0.02	0.182 ± 0.02	0.207 ± 0.02

[a]Values are means ± standard errors.

[b]The number of fish examined during this experiment was 5 for each diet at each sampling period.

Table 11.--Continued

Diet	Time Intervals								
	Satiation	1.5 hrs	2.5 hrs	3.5 hrs	4.5 hrs	6.5 hrs	8.5 hrs	10.5 hrs	12.5 hrs
Experiment B[c]									
					Stomach				
Oregon moist	1.77±0.16	1.50±0.26	1.45±0.07	1.30±0.24	1.04±0.23	0.97±0.17	0.85±0.13	0.74±0.17	0.73±0.17
Ewos	1.59±0.10	...	1.20±0.28	1.26±0.10	1.17±0.25	0.99±0.15	0.93±0.21	0.95±0.10	0.92±0.10
					Intestine				
Oregon moist	0.049±0.02	0.104±0.03	0.070±0.02	0.203±0.03	0.242±0.05	0.26±0.03	0.27±0.03	0.39±0.06	0.33±0.07
Ewos	0.081±0.02	...	0.080±0.02	0.076±0.01	0.225±0.05	0.14±0.01	0.22±0.05	0.29±0.02	0.28±0.05
Oregon moist	n = 5	n = 3	n = 4	n = 4	n = 5	n = 5	n = 5	n = 5	n = 5
Ewos	n = 5	n = 0	n = 4	n = 5	n = 3	n = 4	n = 4	n = 5	n = 4

[c] n = number of fish examined during each sample period.

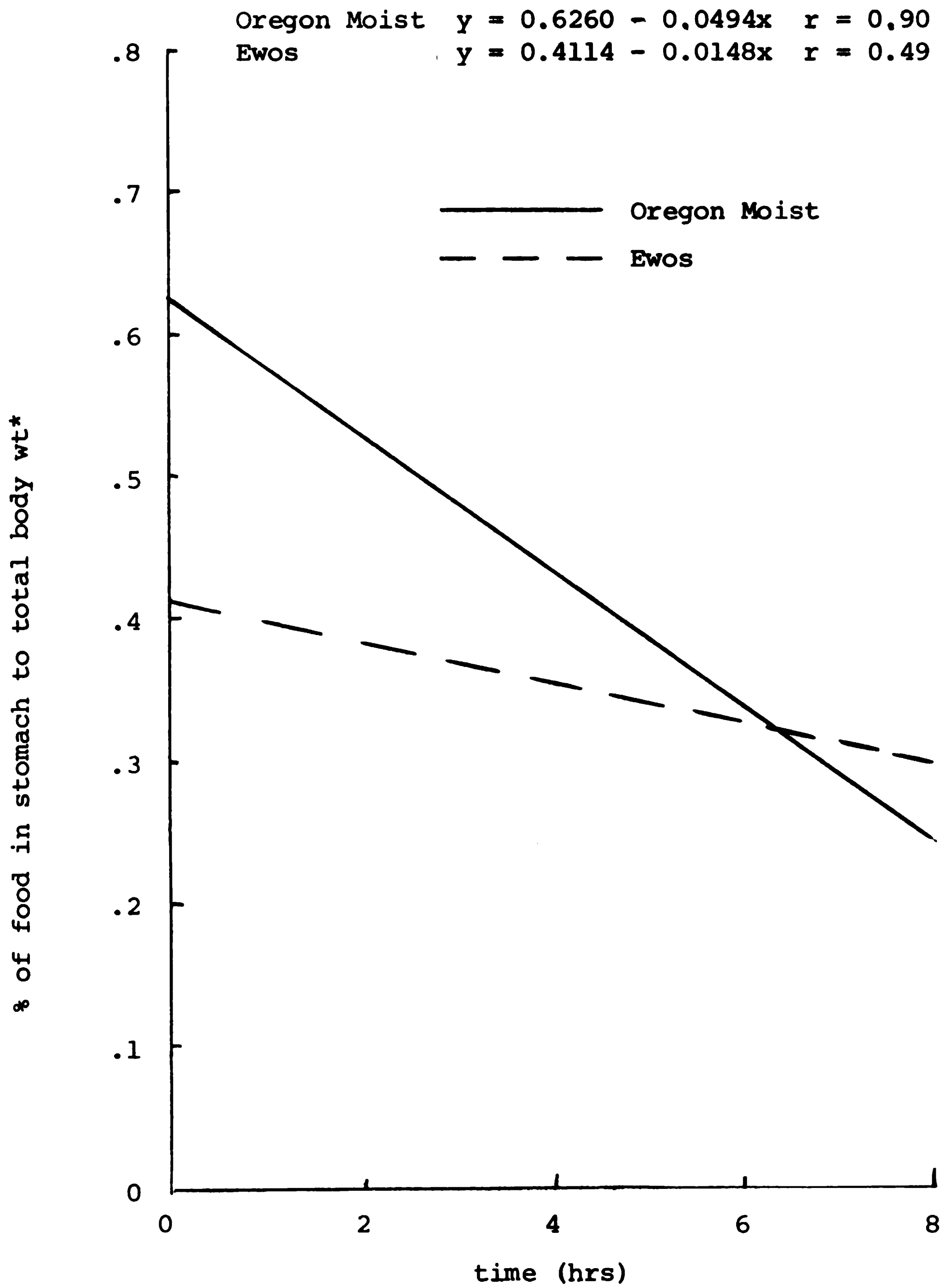


Figure 5. Maximum food consumption and rate of stomach evacuation for Oregon moist and Ewos diets at 13.5 C and dissolved oxygen content equal to 6.2 ppm. (*Stomach contents equal dry wt and body wt equals wet wt.)

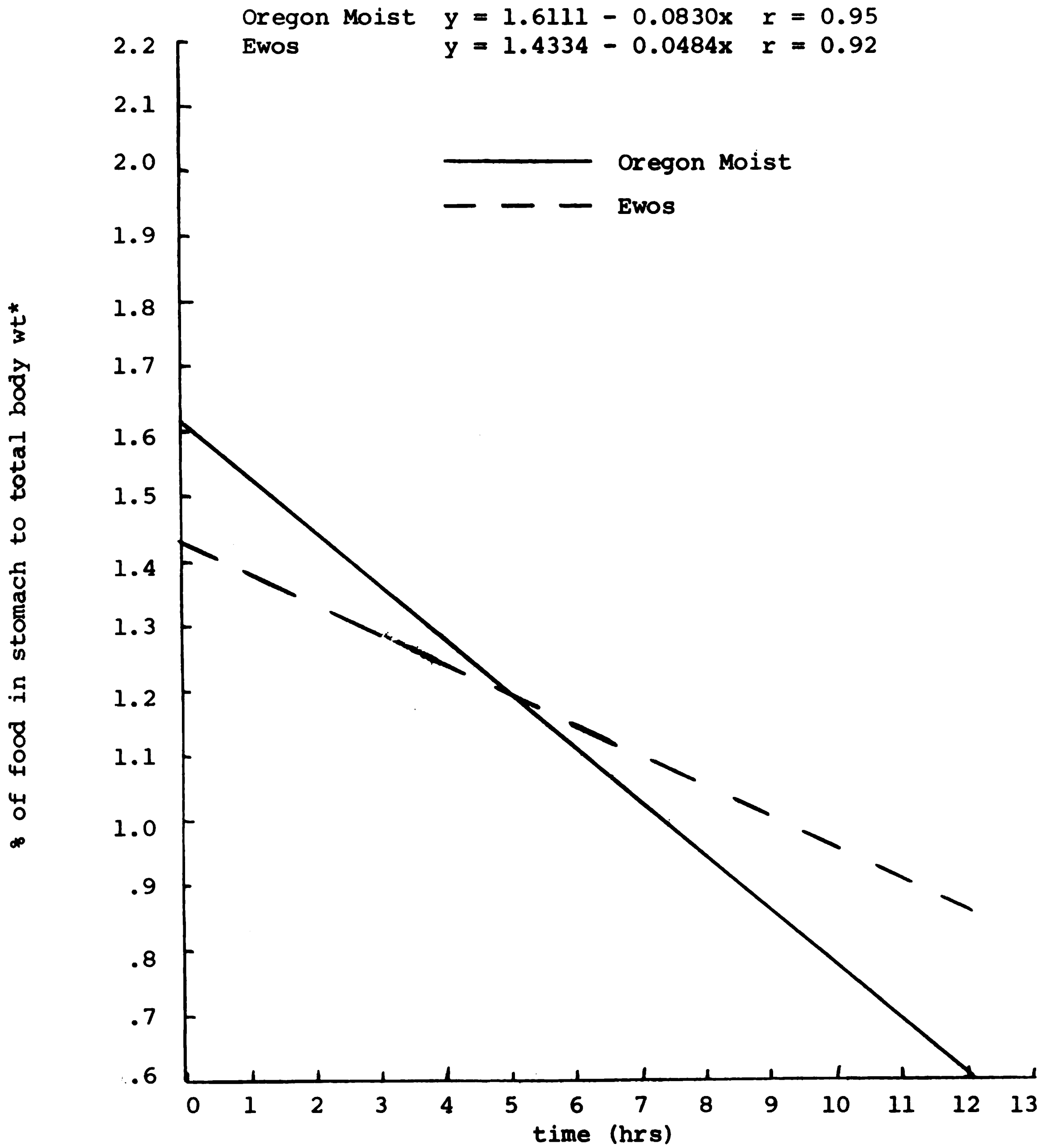


Figure 6. Maximum food consumption and rate of stomach evacuation for Oregon moist and Ewos diets at 16.5 C and dissolved oxygen content of 8.4 ppm. (*Stomach contents equal dry wt and body wt equals wet wt.)

then decrease, with increasing temperature (Warren, 1971). Averett (1969), found that with coho salmon when food was not limiting, consumption increased as the temperature increased from 5 to 17 C. Brett and Higgs (1970) found that sockeye consumed the greatest amount of food when fed to satiation at a temperature between 15-20 C. Thus if temperature were the only variable effecting food consumption, then the fish tested at 16.5 C would be expected to consume more than fish tested at 13.5 C, which was found.

Dissolved oxygen will also affect the amount of food consumed in a given meal. Any reduction in dissolved oxygen levels below air saturation can be expected to reduce food consumption when food is fed in excess (Warren, 1971). Since the DO concentration in the tank held at 13.5 C was 6.2 ppm and the dissolved oxygen in the 16.5 C water was 8.4 ppm, this may also be a reason for the reduced consumption at 13.5 C in comparison to fish tested at 16.5 C.

Fish size affects the amount of food consumed. Brett (1971) found that the amount of food consumed (in proportion to total body weight) in a single meal decreased as fish size increased. Since the average size of fish fed Ewos at both temperatures tested was smaller than fish fed Oregon moist (Table 11), the Ewos fed fish should be expected to consume more in proportion to their body weight than the larger fish fed Oregon moist. Apparently the difference in fish size did not exert a strong influence on the amount of food consumed, for fish fed Ewos consumed less than fish fed Oregon moist at both temperatures tested.

The size and shape of individual food particles fed will also have some effect on the amount of food consumed (Brett, 1971). The pellet size of the two diets were approximately the same, yet the shape was quite different. Oregon moist was a soft rounded pellet and Ewos was a dry, hard irregular shaped particle. This variable may explain the difference in the amount consumed at both temperatures.

Animals tend to eat to satisfy their energy demands so that the caloric content of the food will also affect food consumption (Rozin and Mayer, 1961; Mayer, 1955). The dietary calories were determined in both diets (Phillips and Brockway, 1959). The calories available to the fish in the Ewos diet were 1,226 per pound and in Oregon moist 1,003 per pound. If coho salmon consume food in relation to their energy demands then the fish fed Ewos would be expected to consume less than fish fed Oregon moist, since they can get an equal amount of calories from less amount of food. This may explain the lower amount of food consumed by fish fed Ewos at both temperatures (Table 2).

Digestion rate is also a function of temperature. It does not display a distinct optimum but tends to increase with rising temperature, reaching a maximum rate as the general limit of temperature tolerance is approached (Shrable, Tiemeier and Deyoe, 1969; Smit, 1967; Molnar, Tamassy and Tolg, 1967; Molnar and Tolg, 1962). This might explain the greater rate of digestion at 16.5 C (Fig. 6) when compared to the rate of digestion at 13.5 C (Fig. 5).

The amount of food consumed also affects digestion rate. Hunt (1960) found that the amount of food digested during a given time increases in proportion to the meal size. Windell (1967) suggests that increased food volume may result in increased enzyme and/or acid production in the stomach. Thus the time required to empty the stomach of a given food type remains approximately the same, regardless of the food volume, when other factors are equal. Brett and Higgs (1970) found that at any one temperature, rate of digestion in sockeye appeared to be proportional to the mass of food remaining in the stomach. The larger volume of food consumed by fish fed Oregon moist when compared to fish fed Ewos at both temperatures (Table 11), may be the reason for the greater digestion rate in fish fed Oregon moist.

Other factors known to affect digestion rate in fish, that may explain the difference observed between fish fed Ewos vs. Oregon moist, are differences in substrate relations, such as surface contact and susceptibility to enzyme saturation (Smit, 1967). Composition of the diet may also affect digestion rate (Brett and Higgs, 1970). A decrease occurs when fat content is particularly high, either in live food (mealworms) or artificial diets; final emptying of the stomach is delayed by particles of chitin or the thick exoskeleton of prawns (Kitchell and Windell, 1968). Since fat content is approximately equal in the two diets it is doubtful that this component affected the rate of digestion, yet other components, such as texture, moisture content, shape, etc. may very well be affecting the rate of digestion observed with the two diets.

Since both the amount consumed and the rate of digestion were greater for fish fed Oregon moist, regardless of temperature, it is believed that when given multiple daily meals the fish fed Oregon moist consumed and assimilated much more food than fish fed Ewos. This may be a prime reason why the growth of fish fed Oregon moist was greater than fish fed Ewos at all temperatures tested, since both diets are believed to be complete and balanced diets for coho salmon.

SUMMARY AND CONCLUSIONS

1. The Ewos diet is not as readily accepted as Oregon moist diet at the time when fish first start to feed. While all fish eventually start feeding on Oregon moist, many fish fed Ewos never start feeding. Reduced temperatures seem to increase the percentage of fish fed Ewos that never start feeding.

2. Mortality after the first 10 days of the experiment was greater for fish fed Ewos, in comparison to fish fed Oregon moist, and increased with decreasing temperature. This higher mortality among fish fed Ewos is due to non-feeding fish. Mortality at all temperatures and diets was extremely low once the fish had started to feed.

3. Fat content of all fish fed Oregon moist, regardless of temperature, was greater than fish fed Ewos. For fish fed the same diet, percent fat increased with temperature.

4. During the first 20 days of the experiment the fish fed Oregon moist obtained a higher percent body fat than fish fed Ewos, and the percent increase was greatest at the warmest temperature. After the first 20 days all fish increased in percent body fat at approximately the same rate, regardless of diet or temperature.

5. Mortality in the first 10 days of the experiment was extremely high for fish at all temperatures and diets. Mortality during this period was greater for fish fed Ewos and kept at 12 and 14 C in comparison to fish fed Oregon moist at the same temperatures. The lower mortality in Oregon moist fed fish is believed to be due to the greater acceptance of this food.

6. During the test period of 160 days the greatest amount of growth occurred at 14 C, with fish fed Oregon moist, but their final size was not significantly different than those reared at 17 C.

7. Growth rate appeared to be a function of temperature and fish size. Initial growth (first 80 days of experiment) was greatest at 17 C, regardless of diet. As the fish got larger the growth rate decreased at all temperatures, but more so for the larger fish kept at 17 C in comparison to those kept at 14 C or 12 C. Thus by the end of the experiment the fish kept at 14 C were the largest.

8. The growth rate for fish kept at any given temperature was approximately equal (if non-feeding fish are ignored), for both diets tested. Due to the accumulation of a higher percent fat in fish fed Oregon moist vs. Ewos during the first 20 days of the experiment, and the retention of this higher proportion throughout the experiment, the final weight of fish fed Oregon moist at any given temperature was always greater than those fed Ewos.

9. It is believed that fish were showing definite signs of smolting after 160 days (one fish had completely smolted). No clear distinction between temperature or diet on the time of smolting could be made, since approximately equal numbers (90%) of fish in each treatment were showing signs of smolting. Size of fish did seem to affect smolting, since in all treatments it was the smaller fish that showed no signs of smolting.

10. No decrease in percent body lipid (except in fish fed Ewos and kept at 17 C) was observed with smolting, as has been observed by other workers. Since this phenomenon has only been observed in artificially raised salmonids, and does not occur in wild fish where the diet is adequate with respect to both protein and energy, it is believed that both diets are sufficient with respect to protein and energy, especially when fed in excess.

11. At the two temperatures tested the amount of food consumed and rate of digestion is greater for fish fed Oregon moist in comparison to those fed Ewos. Since greater consumption and faster digestion greatly increases the amount of food processed in a given day, when multiple feedings are made, the amount of food consumed and assimilated by fish fed Oregon moist will be much greater than those fed Ewos. This is believed to be a major factor causing greater growth (% fat and total weight) in fish fed Oregon moist vs. fish fed Ewos.

12. When deciding which diet to feed coho salmon the fish culturist has to consider many things. Cost is an important factor. Since the Ewos diet is produced in a foreign country taxes paid to import it raise its price considerably. Oregon moist is produced only in large quantities eliminating many small producers from using this diet. Oregon moist has to be kept in a freezer where Ewos only has to be stored in a dry and cool location.

If the number of fish one has to start with is limited then the higher initial mortality with Ewos fed fish would become an important factor. Perhaps starting the fish on Oregon moist and then switching to Ewos would be a wiser decision than using either of the diets exclusively.

If the amount of fat in the fish at the time of stocking is important then Oregon moist would be a better diet to feed. Peterson (1971), has shown that a high percent body fat at time of stocking will insure better survival in the natural environment. Other workers believe that low fat levels at time of stocking enhance survival, in this case Ewos would be a better diet to feed.

Another factor to consider is that Ewos tends to provide less trouble in automatic feeders than Oregon moist. Since Oregon moist is moist and sticky it tends to gum-up and clog feeders where Ewos does not.

Ewos pellets float longer than Oregon moist pellets which gives the fish more time to take the food off the surface. Once the food reaches the bottom of the tank it becomes mixed with feces and the fish are reluctant to consume it.

Either diet may provide a distinct taste to the flesh of the fish. If the fish are going to be consumed this factor has to be considered.

As one can see each diet has its advantages and disadvantages and many factors have to be considered when choosing one diet over the other.

LITERATURE CITED

Allen, K. Radway. 1944. Studies on the biology of the early stages of the salmon *(Salmo salar)*. 4. The smolt migration in the Thurso River in 1938. J. Animal Ecol., 13: 63-85.

Association of Official Analytical Chemists. 1960. Methods of analysis. 9th ed. Assoc. Offic. Anal. Chemists, Washington, D.C.

Averett, R.C. 1969. Influence of temperature on energy and material utilization by juvenile coho salmon. Ph.D. thesis. Oregon State University, Corvallis. 74 pp., in C.D. Warren, 1971.

Baldwin, N.S. 1957. Food consumption and growth of brook trout at different temperatures. Trans. Am. Fish. Soc. 86: 323-328.

Black, E.C. 1958. Energy stores and metabolism in relation to muscular activity in fishes, pp. 51-67. In P.A. Larkin (ed.). The investigation of fish-power problems. H.R. MacMillan lectures in fisheries, Univ. of British Columbia, Vancouver, B.C., in J.R. Brett et al., 1969.

Brett, J.R. 1971. Satiation time, appetite, and maximum food intake of sockeye salmon *(Oncorhynchus nerka)*. J. Fish. Res. Bd. Canada 28: 409-415.

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: 1767-1779.

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: 2363-2394.

Brown, M.E. 1957. Experimental studies of growth, pp. 361-400. In M.E. Brown (ed.). Physiology of Fishes, Vol. 1, Academic Press, Inc., New York.

Conte, F.P., H.H. Wagner, J. Fessler, and C. Gnose. 1966. Development of osmotic and ionic regulation in juvenile coho salmon *(Oncorhynchus kisutch)*. Comp. Biochem. Physiol., 18: 1-15.

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

Eisler, R. 1957. Influence of light on the early growth of chinook salmon. Growth, 21: 197-203.

Elson, P.F. 1957. The importance of size in the change from parr to smolt in Atlantic salmon. Can. Fish Culturist, 21: 1-6.

Gerking, S.D. 1955. Influence of rate of feeding on body composition and protein metabolism of bluegill sunfish. Physiol. Zool., 28: 267-282.

Gross, W.L., E.W.Roelofs, and P.O. Fromm. 1965. Influence of photoperiod on growth of green sunfish. *Lepomis cyanellus*. J. Fish. Res. Bd. Canada 22: 1379-1386.

Groves, T.D.D. 1970. Body composition changes during growth in young sockeye *(Oncorhynchus nerka)* in fresh water. J. Fish. Res. Bd. Canada 27: 929-942.

Hablou, W.F., J. Wallis, T.B. McKee, D.K. Law, R.O. Sinnhuber, T.C. Yu. 1958. Development of the Oregon pellet diet. Technical paper No. 1213, Oregon Agricultural Experiment Station.

Haskell, D.C., L.E. Wolf, and L. Bouchard. 1956. The effect of temperature on the growth of brook trout. New York Fish Game J. 3: 108-113.

Hermann, R.B., C.E. Warren, and P. Doudoroff. 1962. Influence of oxygen concentration on the growth of juvenile coho salmon. Trans. Am. Fish. Soc. 91: 155-167.

Hoar, W.S. 1965. The endocrine system as a chemical link between the organism and its environment. Trans. Roy. Soc. Can. Ser. IV, 3: 175-200.

Hoar, W.S. 1939. The weight-length relationship of the Atlantic salmon. J. Fish. Res. Bd. Canada, 4: 441-460.

Houston, A.H. 1961. Influence of size upon the adaptation of steelhead trout *(Salmo gairdneri)* and chum salmon *(Oncorhynchus keta)* to sea water. J. Fish. Res. Bd. Canada, 18: 401-415.

Hunt, B.P. 1960. Digestion rate and food consumption of Florida gar, warmouth, and largemouth bass. Trans. Amer. Fish. Soc. 89: 206-211.

Johnston, C.E., and J.G. Eales. 1970. Influence of body size on silvering of Atlantic salmon *(Salmo salar)* at parr-smolt transformation. J. Fish. Res. Bd. Canada 27: 983-987.

Kitchell, J.F., and J.T. Windell. 1968. Rate of gastric digestion in pumpkinseed sunfish, *Lepomis gibbosus*. Trans. Amer. Fish. Soc. 97: 489-492.

Locke, D.O., and S.P. Linscott. 1969. A new dry diet for landlocked Atlantic salmon and lake trout. Progressive Fish-Culturalist, 31: 3-10.

Love, R.M. 1970. The Chemical Biology of Fishes. Academic Press, London and New York, pp. 51-55, 260-262.

Lovern, J.A. 1934. Fat metabolism in fishes. V. The fat of salmon in its young fresh water stages. Biochem. J. 28: 1961-1963.

Markus, H.C. 1962. Hatchery-reared Atlantic salmon smolts in ten months. U.S. Fish and Wildlife Service, Progressive Fish-Culturalist, Vol. 24, No. 3, pp. 127-130.

Mayer, J. 1955. Regulation of energy intake and the body weight: the glucostatic theory and the lipostatic hypothesis. In R.W. Miner (ed.). The regulation of hunger and appetite. Ann. N.Y. Acad. Sci. 63: 15-43.

Molnar, Gy., E. Tamassy, and I. Tolg. 1967. The gastric digestion of living, predatory fish, pp. 135-149. In S.D. Gerking (ed.). The Biological Basis of Freshwater Fish Production. Blackwell Scientific Publication, Oxford and Edinburgh, England.

Molnar, Gy., and I. Tolg. 1962. Relation between water temperature and gastric digestion of largemouth bass *(Micropterus salmoides)*. J. Fish. Res. Bd. Canada 19: 1005-1012.

Parker, R.R., and W.E. Vanstone. 1966. Changes in chemical composition of central British Columbia pink salmon during early sea life. Ibid., 23: 1353-1384.

Peterson, Hans H. 1971. Further results in the rearing of one year old smolts of Atlantic salmon in heated water. Report from Aktiebolaget Ewos Co. of Sodertalje, Sweden.

Phillips, Arthur M., Jr., and Donald R. Brockway. 1959. Dietary calories and the production of trout in hatcheries. Progressive Fish-Culturalist, 21: 3-16.

Phillips, A.M., H.A. Podoliak, H.A. Poston, D.L. Livingstone, H.E. Booke, E.A. Pyle, and G.L. Hammer. 1963. The relationship of protein and ash in water and fat free samples of fish tissues. Fish. Res. Bull. N.Y. 26: 49-51.

Pyle, E.A. 1969. The effect of constant light or constant darkness on the growth and sexual maturity of brook trout. Cortland Hatchery Report No. 36 for the year 1967. Fish. Res. Bull. No. 31, State of New York Cons. Dept. Albany, New York.

Rozin, P., and J. Mayer. 1961. Regulation of food intake in the goldfish. Am. J. Physiol. 201: 968-974.

Shrable, J.B., O.W. Tiemeier, and C.W. Deyoe. 1969. Effects of temperature on rate of digestion by channel catfish. Progressive Fish-Culturalist, 31: 131-138.

Smit, H. 1967. Influence of temperature on the rate of gastric juice secretion in the brown bullhead *(Ictalurus nebulosus)*. Comp. Biochem. Physiol. 21: 125-132.

Vanstone, W.E., and J.R. Market. 1968. Some morphological and biochemical changes in coho salmon, *Oncorhynchus kisutch*, during parr-smolt transformation. J. Fish. Res. Bd. Canada 25: 2403-2418.

Vinogradov, A.P. 1953. The elementary chemical composition of marine organisms. Efron and Sellow (translators). Yale Univ. Press, New Haven, Conn., pp. 463-566, in J.R. Brett et al., 1969.

Warren, Charles E. 1971. Biology and Water Pollution Control. W.B. Saunders Company, pp. 135-167.

Warren, C.E., and G.E. Davis. 1967. Laboratory studies on the feeding, bioenergetics and growth of fish, pp. 175-214. In S.D. Gerking (ed.). The Biological Basis for Freshwater Fish Production. Blackwell Scientific Publications, Oxford.

Windell, J.T. 1967. Rates of Digestion in Fishes, pp. 151-173. In The Biological Basis of Freshwater Fish Production, S.D. Gerking (ed.). Blackwell Sci. Pub., Oxford.

APPENDIX A

CHEMICAL ANALYSIS OF WELL WATER USED IN EXPERIMENT

APPENDIX A

CHEMICAL ANALYSIS OF WELL WATER
USED IN EXPERIMENT

(From Institute of Water Research,
Michigan State University)

Alkalinity mg $CaCO_3$/liter	331
Ammonia mg N/liter	0.12
Chloride mg Cl/liter	0.6
Copper mg Cu/liter	<0.01
Hardness mg $CaCO_3$/liter	322
Iron mg Fe/liter	0.1
Lead mg Pb/liter	<0.1
Conductivity micro mhos/cm	650
Nitrate mg N/liter	0.00
Nitrite mg N/liter	0.00
Phosphorus total mg P/liter	0.13
Sulfate mg SO_4/liter	4.0
Zinc mg Zn/liter	<0.015

APPENDIX B

COMPOSITION OF THE DIETS USED IN THE EXPERIMENT

APPENDIX B

COMPOSITION OF THE DIETS USED IN THE EXPERIMENT

EWOS (from Locke and Linscott, 1969)

	Starter Feed (Type F48) (%)	Grower Feed (Type F49) (%)
Crude protein	58	47.0
Fat	8	4.9
Ash	15	10.4
Water	7	6.5
Fiber	1	1.5
Carbohydrate	11	29.7
Vitamins[1]	..	..
Minerals[2]		

[1]Vitamin A, vitamin D, vitamin E, vitamin K (menadion), vitamin B1 (aneurine), vitamin B2 (riboflavine), vitamin B6 (pyridoxine), vitamin B12 (cyanocobamine), niacin, calcium pantothenate, vitamin H, vitamin C (ascorbic acid).

[2]The product contains all necessary minerals and trace elements.

OREGON MOIST (from Hublou et al., 1958)

	(%)
Tuna viscera, frozen	20.0
Turbot, frozen	20.0
Cottonseed oil meal	26.4
Herring meal	18.0
Crab solubles	5.4
Wheat germ meal	3.6
Distiller solubles	2.4
Corn oil	1.8
Vitamin mixture[1]	2.3
Antioxidant (Tenox VI)	0.1

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[1]Ascorbic acid, biotin, calcium pantothenate, choline cholride, folic acid, inositol, menadione, niacin, para-aminobenzoic acid, pyridoxine hydrochloride, thiamine hydrochloride, B-12 supplement, E supplement.

Proximate Analysis of Oregon Moist (taken from the analysis given on the container):

Crude protein	not less than	35.0%
Crude fat	not less than	5.0
Crude fiber	not more than	4.0
Moisture	not more than	35.0

APPENDIX C

METHOD FOR FAT ANALYSIS

APPENDIX C

METHOD FOR FAT ANALYSIS

The oven dried sample (∿ 10-15 g) plus the tared aluminum pan were placed in a 250 ml beaker containing 150 ml of hexane. The dried sample was then crushed (if the sample was crushed before it was put in the hexane it tended to splatter, and some of the sample was lost) and allowed to stand in the hexane for 24 hrs, at which time the hexane plus dissolved lipid was carefully drawn-off. The sample was then further extracted with three successive 150 ml portions of hexane, each extraction lasting for 24 hrs. After the final extraction as much of the hexane was drawn-off as possible, without losing any of the residue remaining. The remaining hexane and residue were then filtered through a tared filter paper, which was washed with 25 ml of hexane. The tared aluminum pan plus the tared filter paper containing the residue were then placed in the drying oven at 105 C overnight to remove final traces of hexane, and then weighed. Brett et al. (1969) followed a procedure similar to this to remove lipid from sockeye flesh.

APPENDIX D

METHOD FOR ASH ANALYSIS

APPENDIX D

METHOD FOR ASH ANALYSIS

Two drops of pure olive oil were added to the dried samples and then most of the fat was removed by heating over a Bunsen burner. The sample was then placed in a combustion oven for two hours at a temperature of 650 C. The samples were removed, a few drops of distilled water added, and put back in the oven at 650 C for an additional half-hour, and then weighed. It was found that the aluminum pans lost a small amount of weight when placed in the oven at 650 C. In order to compensate for this the pans were put in the oven at 650 C for one hour before being weighed and the samples put into them.

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