USE OF HEATED SEA WATER FOR FARMING OYSTERS AND SALMON

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Prepared By

Department of Fisheries and Wildlife

Oregon State University

INTRODUCTION

The following is a report of the current status of a study of the feasibility of utilizing the heated effluent from coastal nuclear power plants for the culture of salmon and oysters. The work is being conducted by Oregon State University, Department of Fisheries and Wildlife with assistance from other departments. Portland General Electric, Pacific Power and Light and the Eugene Water and Electric Board are jointly funding the study. Additional support was provided by the National Oceanographic and Atmospheric Administration through its Sea Grant program. Work was begun in the spring of 1971. This phase of the study is scheduled for completion in the summer of 1974.

This report emphasizes interpretation of results obtained from experiments completed since our last status report was submitted in February of 1973. This is not a final report. It is based on the best data currently available to us. In the light of more recent work our thinking has changed somewhat with regard, for example, to the seriousness of the disease problem with salmon cultured at temperatures above ambient. Some of our conclusions, based primarily on work done in 1973, may differ to a certain extent from statements that we made earlier based on our preliminary studies.

Data contained in this report are intended for the use of the granting agencies only. Since some of these data will constitute a portion of three graduate theses (those of Bernard Kepshire, Robert Malouf, and Gerald Rowan) publication elsewhere of material contained in this report must have the prior approval of O. S. U.'s Department of Fisheries and Wildlife.

We want to emphasize that this is not a final report. This work is still in progress, and significant advances in our understanding of the growth and disease phenomena under study, as well as in our culture methodology, are certainly possible.

SUMMARY

Oyster Studies

1) A series of experiments was conducted to study the combined effects of temperature and water flow rate on the shell and meat growth of oysters of various sizes.

2) Some of these experiments also provide a comparison between oyster growth in an open coastal location (Port Orford) and a largely estuarine water source (Newport).

3) Seasonal differences in the growth response of oysters to a given temperature-water flow combination indicate that the food content of the water varies considerably. Efforts are now underway to monitor this seasonal variation directly.

4) Differences in growth were observed between the two locations tested. Larger oysters seemed to grow better in Newport, but we noted our best spat growth in Port Orford. It is likely that seasonal growth differences at a given site are at least as great as the differences between two sites as long as water flow is not limiting to growth.

5) We found that shell growth and meat growth are two different phenomena that should be considered separately.

6) There is good evidence from our experiments to show that the growth of oysters can be significantly improved by increasing temperatures at least up to 20^{o}C. However, our data show that if the increased temperatures are accompanied by decreased food availability, either due to inadequate flow rates or seasonal changes in natural food supplies, decreased growth and high mortalities will result.

7) From our data using juvenile oysters (about 0.1 g wet meat weight) we would recommend a flow rate of about 20 ml/min/oyster at 20^{o}C. This means, assuming

equivalent circulation and exchange, that one million of these oysters would require roughly 5,000 gpm.

8) Our estimated water flow requirement is more than three times greater than previously published estimates.

9) Our water requirement estimate will be refined by future studies. In these studies we will look at seasonal changes in food availability, differences in requirements of oysters of various sizes, and possibly at genetic differences in requirements.

Fish Studies

1) We conducted two temperature x ration factorial experiments during the spring and summer of 1973 to study the combined effects of temperature and food on growth and survival in chum salmon.

2) These experiments showed that the amount of food required just to maintain the fish with no weight gain or loss was considerably higher at the higher temperatures. Consequently, the percentage of the food consumed by the fish that eventually contributed to weight gain (conversion efficiency) was lower at high temperatures.

3) We found the best growth in fish reared at high ration levels (about 15% of body weight per day) and at about 14°C (57°F).

4) Temperatures above 14°C produced lower growth rates and increased susceptibility to disease.

5) Recognizing our limited ability to control disease in salmon, it does not appear that the warm water culture of these fish is technically feasible at this time. Only if disease control methods are improved, and if the costs of these control methods are not prohibitive, will the culture of chum salmon in salt water at temperatures up to about 60°F show promise of success.

6) Disease control experiments, including monitoring Bacterial Kidney Disease and Vibrios as well as Vibrio vaccination studies showed that disease (particularly Vibrio) was our most serious obstacle.

7) Vaccination to control Vibrio was only partially successful. Improved techniques will be employed in future work to further evaluate the potential of vaccination as means of controlling Vibrio in cultured salmonids.

OYSTER GROWTH STUDIES

Introduction

Research dealing with oyster growth at elevated temperatures was begun at the Marine Science Center in Newport in 1970 and at the Marine Research Laboratory in Port Orford in 1971. In general terms this work was intended to assess the biological and economic feasibility of utilizing the heated saline effluent from coastal nuclear power plants for commercial oyster culture. To that end research has been conducted to define the relationship between water flow rate and oyster growth at various temperatures. These relationships were intended, then, to provide a means of estimating the capacity of unenriched sea water at various temperatures to support the growth of oysters.

A number of experiments have been conducted at the two research stations over the past three years. Some of the experiments were carried out only at one location (Port Orford or Newport). Others were duplicated at each laboratory to provide a comparison between the two water sources. These experiments will be described and discussed in chronological order in hopes of providing an understanding of the rationale behind design changes in successive experiments. Work in progress will be described, and future research plans will be presented.

Preliminary Studies

Preliminary work conducted for the most part at the Port Orford laboratory was designed to determine if juvenile oysters would grow or even survive in full strength sea water. The work was also intended to determine what effect temperature might have on growth and survival under conditions in which water flow was not limiting.

These initial experiments provided evidence that juvenile oysters survive well in high salinity water and that their growth can be enhanced by elevated temperatures.

This work also provided our first indications that the growth of oysters at any temperature varies considerably with season. We found that there were periods of the year (Sept.-Oct.) when the oysters simply did not grow regardless of the water flow rate or the temperature.

The results of these preliminary studies were described in our first progress report (May 1, 1972) and will be reviewed in detail in our final report.

Growth Experiments

In 1973 a second series of experiments was conducted. These experiments were intended to offer a comparison of the capacity of two saline water sources (Port Orford and Newport) to support the growth of oysters. The experiments were further intended to investigate the relationship between water flow, oyster growth, and temperature in the two locations.

In the descriptions and discussions that follow, the experiments are designated as follows:

Experiment I	- Port Orford	Jan. 16, 1973 to March 12, 1973
Experiment I	- Newport	Jan. 23, 1973 to March 18, 1973
Experiment II	- Port Orford	April 7, 1973 to June 22, 1973
Experiment II	- Newport	March 30, 1973 to June 22, 1973
Spat Experiment I	- Port Orford	May 27, 1973 to June 24, 1973
Spat Experiment I	- Newport	May 25, 1973 to June 22, 1973
Experiment III	- Newport	Oct. 11, 1973 to Dec. 15, 1973

All of these experiments, except those designated as "spat" experiments, were conducted with single "cultchless" oysters of a relatively uniform initial size. In the spat experiments, smaller oysters (spat) attached to shell cultch were used.

Experiment I - Port Orford Jan. 16, 1973-March 12, 1973

Objective

This experiment had two objectives. These were: 1) to investigate the relationship between water flow rate, temperature, and oyster growth; and 2) to provide growth data for comparison with data from oysters grown concurrently in Newport.

The design of this experiment was described in detail in our status report of Feb. 5, 1973. Basically, the experiment was a 4 x 4 factorial design (four temperatures and four water flow rates in all possible combinations). The temperatures used were 50^{o}, 60^{o}, 65^{o}, and 70^{o}F (i.e. about 10^{o}, 15^{o}, 18^{o}, 21^{o}C). Water flow requirements for this first experiment were estimated from a broad range of values that appear in the literature (75 to 175 ml/min/50 oysters for oysters of the size used). We used flows of 50, 100, 200, and 400 ml/min/50 oysters to cover the range of values reported in other studies.

Shell growth, as shell length only, was determined on the basis of biweekly measurements of 35 randomly-selected oysters from each of the 16 treatments. Meat growth, as a change in wet meat weight, was determined by weighing the meats from 50 oysters randomly selected from the same large group and at the same time as the experimental animals. Then, at the end of the experimental period, 35 oysters from each treatment were shucked and weighed. Growth was expressed as the difference between the initial mean weight and the final mean weight for each treatment.

Results

Shell growth was found to be minimal in all treatments; there was essentially no shell growth during the experiment. The changes in meat weight, both positive and negative, are shown in Table 1. As with shell length, meat growth (gain or loss) was very slight during the 40 day experiment. As might be expected during periods of low food availability, the greatest increases (or the least decreases) in weight were at the lowest temperature.

Mortalities during the experiment were quite high (Table 2), and were somewhat higher at the higher temperatures.

We can speculate that under conditions that are nutritionally inadequate, as our growth data show these to be, factors such as high temperature, that contribute additional stress on the animals increase their rate of mortality.

Experiment I - Newport Jan. 23, 1973-March 18, 1973

Objective

To provide a growth and survival comparison with open-coast waters (Port Orford).

Design

Again, details of the design were given in our second status report (Feb. 5, 1973). Basically, what we attempted to do was to duplicate in Newport a portion of the experimental array that we had in Port Orford and to run an experiment concurrently with the Port Orford experiment.

The oysters used in the experiment were randomly drawn from the same "pooled" group as the Port Orford oysters. The oysters were placed in each of four stacks of five trays (modified Heath incubators). Each stack received water of a different temperature (50°, 60°, 65°, 70°F), but at the same flow rate. Since the flow-ml/min/50 oysters

		50	100	200	400	$\bar{X}$
Temp. °C	10°	+0.04	-0.01	+0.05	+0.06	+0.04
	15°	-0.01	-0.02	+0.00	+0.02	0.00
	18°	0.00	-0.01	+0.02	-0.01	0.00
	21°	+0.01	0.00	+0.02	-0.01	+0.01
	$\bar{X}$	+0.01	-0.01	+0.02	+0.04	

Table 1. Port Orford Experiment I. Jan. 16-March 12, 1973.
Change in wet meat weight
(initial wet meat weight = 0.18g)

flow-ml/min/50 oysters

		50	100	200	400	Mean/ temp.
Temp. °C	10°	26%	26%	30%	28%	28%
	15°	36%	22%	34%	38%	33%
	18°	28%	40%	40%	46%	39%
	21°	32%	34%	54%	58%	45%
	Mean/ flow	31%	31%	40%	43%	

Table 2. Port Orford Experiment I. (Jan. 16-March 12, 1973)
Total percent mortality over 40-day experimental period.

water received by each stack of trays flowed down from one tray to another, only the upper tray in a stack was considered comparable to the Port Orford experiment.

The water flow rate used for each temperature was 1,000 ml/min. Since 125 oysters were used in the first tray the water flow per oyster was equivalent to the highest flow rate used in Port Orford (8 ml/min/oyster).

Results

Growth in this experiment was measured on the basis of increase in shell length only. The results of these measurements are given in Table 3. As in the Port Orford experiment, growth was slight and not clearly related to temperature.

Mortality data, given in Table 4, show an increase in mortality at elevated temperatures. This pattern of mortality was, again, probably a response to the stress of low food availability combined with increased temperatures.

Experiment II - Port Orford April 7, 1973-June 22, 1973

Objectives

The second pair of experiments was essentially a repeat of the first pair. The objectives and design were, with few exceptions, unchanged.

Design

As in Experiment I but with minor improvements in the apparatus to provide improved reliability. The oysters used were drawn from the same group as the first experiment. Oysters used in the first experiment were not returned to the pooled group at the termination of the experiment. So, although the source was the same, different oysters were used in the two experiments.

Results

Table 5 shows the change in mean wet weight for each of the 16 combinations flow, ml/min (50 oysters/treatment)

Temp. °F	50	100	200	400	$\overline{X}$
50°	0.00	-0.03	+0.11	+0.24	+0.08
60°	-0.05	+0.02	+0.06	+0.22	+0.06
65°	0.00	0.00	+0.03	+0.07	+0.03
70°	-0.05	+0.02	-0.01	+0.07	+0.01
$\overline{X}$	-0.03	+0.01	+0.05	+0.15	

Table 5. Change in mean wet meat weight (growth) in grams. Port Orford Experiment II, April 7 - June 22, 1973. (initial wet meat weight 0.22 g - n = 70)

flow, ml/min (50 oysters/treatment)

Temp. °F	50	100	200	400	mean/ temp.
50°	16%	20%	22%	16%	19%
60°	44%	30%	38%	40%	38%
65°	80%	70%	66%	46%	66%
70°	74%	88%	68%	66%	74%
mean/ flow	54%	52%	49%	42%	

Table 6. Percent mortality for each of the 16 temperature x flow combinations used in Port Orford Experiment II. Means for the four temperatures and flows are also given.

of temperature and flow used in Experiment II. The results of the experiment were very similar to the first Port Orford experiment (compare Tables 1 and 5) as far as general relationships are concerned, but growth was somewhat better in the second experiment. As in the first experiment, the combination of temperature and flow that yielded the best growth and the highest percent survival (Table 6) was the lowest temperature and the highest flow 50^{o}F x 400 ml/min/50 oysters). Meat growth showed a consistant inverse relationship with temperature and a direct relationship with flow rate.

Mortalities were quite high at the two high temperatures, particularly at the lower water flows. The indications are that this extreme mortality is a stress phenomenon. Plotting growth rate against water flow (Fig. 1) shows that even our highest flow rate cannot be considered to be excess. Even at the lowest temperature there is no indication from our data that 400 ml/min/50 oysters is a sufficient volume to support maximum growth. We may surmise, then, that at higher temperatures the oysters were receiving an inadequate water flow and were further stressed by elevated temperatures. This stress combination was reflected in increased mortality and reduced growth.

It seems from these experiments that the water flow data appearing in the literature and around which the experiments were designed, grossly underestimate the water requirements of oysters in an open coastal location.

Newport Experiment II March 30-June 22, 1973

Objective

As in Newport Experiment I.

Design

With minor improvements, unchanged from Newport Experiment I. Unlike

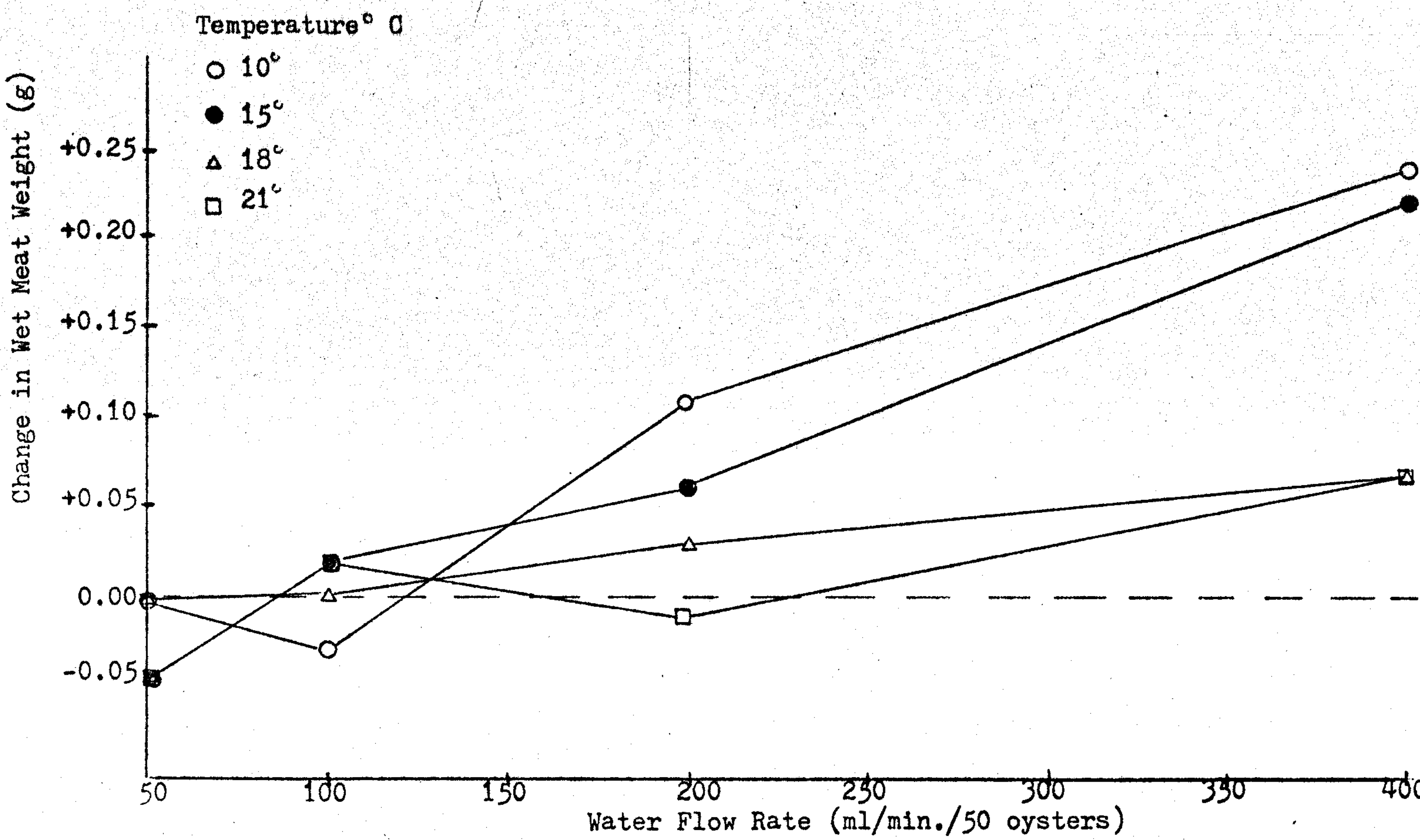

Figure 1. Relationship between water flow rate and change in wet meat weight of oysters held at four temperatures. Port Orford Experiment II - April 7,1973-June 22,1973. The oysters had a mean wet meat weight of 0.22 g. at the start of the experiment.

Experiment I, meat weight data were taken for this experiment to provide a better comparison with Port Orford Experiment II.

Results

Growth data from this experiment (Table 7) show some important differences between our Newport and Port Orford water sources. Growth in Experiment II was considerably better than in previous experiments (compare Tables 3 and 7) and was certainly better than the growth observed in our concurrent Experiment II in Port Orford (compare Tables 5 and 8). Since other factors remained relatively unchanged (temperatures, flows, etc.) the improved growth was probably due to an increase in the food content of the Newport water during the spring months.

Notice (Table 9) that the apparent increase in natural food was also reflected by a significant reduction in mortality (compare Tables 4 and 9). Keeping in mind that the water flow in these experiments was from tray 1 to tray 2, etc. further evidence of the effects of food and temperature stress is provided in Table 9. Note, for example, the great difference in mortality between the first tray position, in which food was at least adequate for growth, and subsequent tray positions. Table 9 also shows an added stress from elevated temperatures so that the least growth and highest mortality is found at the highest temperature 70°F) and the lowest tray position.

Spat Experiment I. Port Orford May 27-June 24, 1973

Objective

To determine the influence of temperature on shell growth and survival of oyster spat held in a water flow rate considered to be excess for their requirements. To provide a comparison with the growth of larger, single oysters held under identical conditions at the same time, and, similarly, with spat being grown in Newport.

Newport Expt. II - March 30 - June 22, 1973

		initial length (mm)	final length (mm)	increase (mm)	% increase
Temp. °F	50°	26.4	32.0	5.6	21%
	60°	26.1	32.5	6.4	25%
	65°	25.1	31.1	6.0	24%
	70°	25.6	30.1	4.5	18%

Table 7. Shell growth (length in mm) from Experiment II, Newport. Flow of 1L/min/125 oysters. Comparable with highest flow rate in Port Orford Experiments I and II (8 ml/min/oyster) and with Experiment I, Newport.

		tray position 1	2	3
Temp. °F	50°	+0.22	+0.08	-0.03
	60°	+0.32	+0.02	-0.04
	65°	+0.30	0.00	+0.02
	70°	+0.35	+0.08	-0.07

Table 8. Change in wet meat weights, in grams, Experiment II, Newport as influenced by temperature and tray position. Water flow was from tray 1 through tray 2 to tray 3 in sequence at each temperature.

		tray position 1	2	3
Temp. °F	50°	13%	30%	28%
	60°	14%	44%	42%
	65°	14%	50%	48%
	70°	14%	68%	86%

Talbe 9. Percent mortality, Experiment II Newport, as influenced by temperature and tray position.

Design

Two hundred spat attached to flat shell pieces were selected for their relatively uniform size and even distribution on the shells. All other spat were removed from the shells. Shell pieces holding a total of 50 spat were placed in shallow trays receiving 400 ml/min at each of four temperatures, 50°, 60°, 65°, and 70°F. Weekly measurements were made of the length and width of all of the 50 spat at each temperature.

Results

Growth and mortality data for this experiment (Table 10 and Fig. 2) shows exactly the opposite relationship found with larger oyster kept at Port Orford at the same time (Table 5). The data indicate that the shell growth of spat can be enhanced considerably by elevated temperatures, and that as long as flows (food) are adequate survival is not adversely affected by the higher temperatures.

Recall that the larger oysters being held under the same conditions at the same time showed little or no shell growth and suffered high mortalities at higher temperatures. The positive effect of temperature on the smaller oyster lends support to our previous statement that the negative influence of elevated temperatures on the larger oysters was associated with an inadequate food supply, and was not a simple temperature effect.

Spat Experiment I. Newport May 22-June 24, 1973

Objective

As in Port Orford Spat Experiment I.

Design

As in Port Orford Spat Experiment I. Spat used were taken from the same stock and at the same time as the Port Orford experiment.

Port Orford - Spat Experiment I - May 27-June 24, 1973

Temp. °F	initial length	final length	increase (mm)	% increase	% mort.
50°	4.70	6.6	1.9	40%	6%
60°	4.1	9.3	5.2	127%	10%
65°	4.1	10.3	6.2	151%	2%
70°	4.1	10.5	6.4	156%	0%

Table 10. Shell growth and mortality of attached spat as influenced by temperature, Port Orford, May 27 - June 24, 1973. Flow rate of 400 ml/min/50 spat. Values are means of 50 measurements.

Newport - Spat Experiment I - May 25 - June 22, 1973

Temp. °F	initial length	final length	increase (mm)	% increase	% mort.
50°	3.7	5.7	2.0	54%	2%
60°	3.7	5.9	2.2	59%	5%
65°	3.9	6.7	2.8	71%	0%
70°	3.7	5.8	2.1	56%	2%

Table 11. Shell growth and mortality of attached spat as influenced by temperature, Newport. May 25-June 22, 1973. Flow rate of 400 ml/min/50 spat. Values are means of 50 measurements.

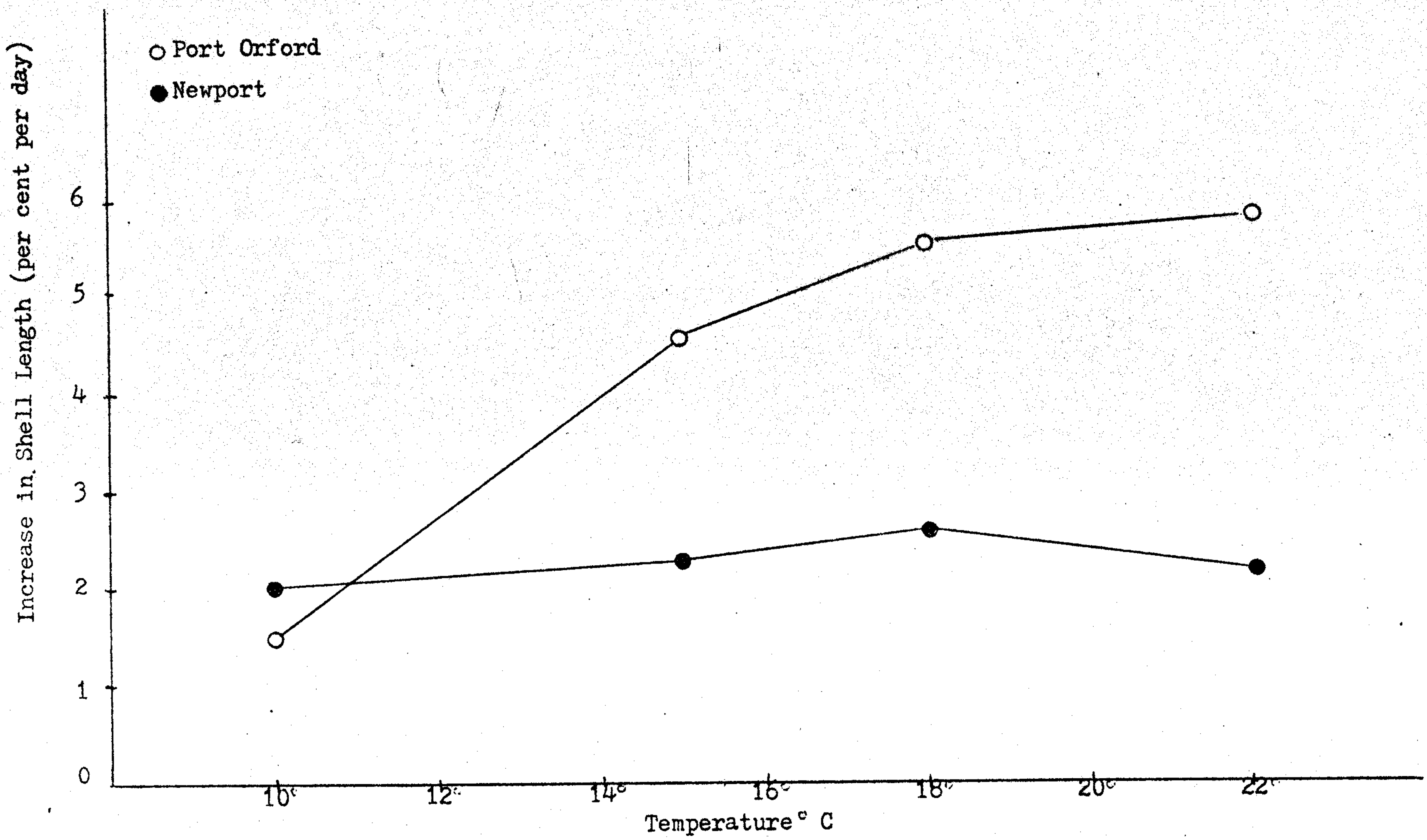

Figure 2. Relationship between temperature and shell growth of oyster spat (about 4 mm initial length) held in Port Orford and Newport. May 25- June 22, 1973.

Results

Spat growth in this experiment (Table II and Fig. 2) showed the same general trend as Newport Experiment II, which was conducted concurrently with larger oysters (Table 7). Unlike the Port Orford spat experiment, the Newport experiment did not show any particular growth advantage due to elevated temperatures. On the other hand there was no evidence of reduced growth or increased mortality at higher temperatures.

Experiment III. Newport Oct. 11-Dec. 15, 1973

In an effort to refine our estimate of the temperature x water flow x oyster growth relationships that have been previously discussed, we initiated a new series of experiments in Newport in the fall of 1973. The emphasis in this series of experiments is on improving our measurement of oyster growth and on efforts to assess the food content of the water by measuring certain parameters directly.

Objective

The experiment consists of a number of parts each having its own objective and contribution to the more general purpose of the experiment. The objective of the experiment as a whole was to provide data that will permit improved definition of the water flow requirements of oysters at various temperatures.

Design

The experiment consisted basically of two separate factorial designs. The first of these was a temperature (11^{o}C, 15^{o}C, 20^{o}C) x water flow (100, 200, 400, 800 ml/min/25 oysters) factorial design. Note that the water flows per oyster used in this experiment are as much as 4 times greater than those previously used for oysters that were larger than the oysters used here.

Date	Carbon mg/L 100% filtered	Carbon mg/L unfiltered	Chlorophylla μg/L 100% filtered	Chlorophyll a μg/L unfiltered
11/1	1.40	1.70	0.97	2.27
11/6	1.90	2.60	0.82	2.12
11/7	1.40	2.05	0.97	2.04
11/11	2.13	2.83	1.40	2.94
11/16	2.93	3.47	1.19	1.86
11/19	2.07	2.00	0.59	1.19
11/21	2.23	1.83	0.64	1.54
11/27	1.73	1.97	0.84	1.48
11/28	1.63	2.07	0.88	1.72

reduction by filtration = 15%

reduction by filtration = 51%

Table 12. Results of total organic carbon and chlorophylla analysis on water samples drawn during Experiment III, Newport. Oct. 11-Dec. 15, 1973. Each value is the mean of three subsamples.

flow (ml/min/25 oysters)

		100	200	400	800
Temp.	11°C	-.037	-.028	-.008	+.002
	15°C	-.040	-.001	+.016	+.035
	20°C	-.032	-.022	+.029	+.040

Table 13. Change in the mean wet weight (in grams) of shucked oyster meats as influenced by temperatures and flow. Values are means of 25 determinations. Initial wet weight = 0.119 g.

particle size less than five microns. All of this organic carbon, even the dissolved materials, should be considered a potential food source for oysters. The chlorophyll data indicate, as might be expected, that chlorophyll is associated with particulate matter (phytoplankton). The data further show that chlorophyll and therefore living phytoplankton did not constitute a large percentage of the total organic carbon in our water source. This experiment was conducted during a time of the year when phytoplankton densities could be expected to be low in Yaquina Bay. But, the fact is the oysters did show increases in meat weight (Table 13). This may mean that they were able to utilize organic carbon from sources other than living phytoplankton.

The growth results for the flow x temperature experiment (Table 13, Fig. 3) show a number of significant features. Unlike most of our previous studies, excellent meat growth was obtained at elevated temperatures. Keep in mind that we used water flow rates that on a per oyster weight basis were as much as eight times greater than any we had previously used. The leveling off of the growth curves if Fig. 3 indicates that our highest flow was approaching excess (i.e. further increases in flow would probably not have appreciably increased growth).

The best growth, both of meat (Table 13) and shell (Table 14), was obtained at 20°C, our highest temperature; but that growth was not significantly greater than the growth observed at 15°C. In any case, there was a distinct growth enhancement at temperatures exceeding ambient.

It is significant to note that there were no mortalities in any of the treatments in this experiment. This is probably due to the increased flow rates (even our lowest flow was 4 times greater than our previous low flow), and to the relatively shorter duration of the experiment.

		flow (ml/min/25 oysters)				
		100	200	400	800	$\bar{X}$
Temp.	11°C	2.0%	3.6%	7.7%	12.4%	6.4%
	15°C	2.6%	7.5%	12.6%	18.8%	10.4%
	20°C	2.8%	4.6%	8.4%	26.7%	10.6%
	$\bar{X}$	2.5%	5.2%	9.6%	19.3%	

Table 14. Percent increase in shell length as influenced by flow rate and temperature. Newport Experiment III Oct. 11-Dec. 15, 1973.

		100% filtered	75% filtered	50% filtered	un-filtered	$\bar{X}$
Temp.	11°C	+.027	+.024	+.022	+.007	+.020
	15°C	+.046	+.013	+.007	+.052	+.030
	20°C	+.004	+.025	+.036	+.059	+.031
	$\bar{X}$	+.026	+.021	+.022	+.039	

Table 15. Change in meat wet weight in grams of shucked oyster meats as influenced by percentage of 5 micron filtration of water supplied to the oysters at 800 ml/min/25 oysters. Newport Experiment III. Oct. 11 - Dec. 15, 1973.

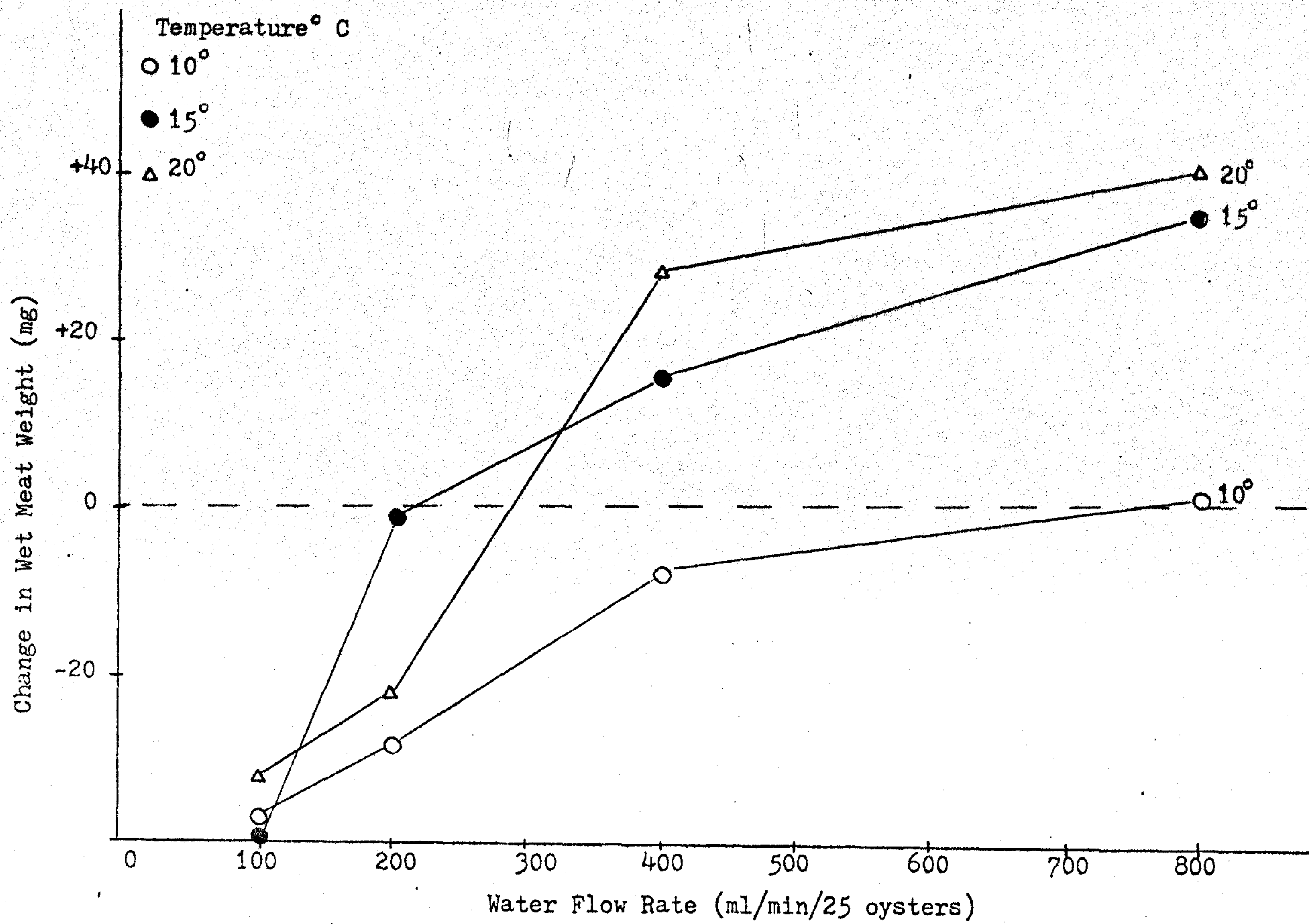

Figure 3. Relationship between water flow rate and the change in wet meat weight of oysters held at three temperatures. Newport Experiment III, Oct. 9- Dec. 5,1973. Initial wet weight was 119 mg.

The filtration experiment did not show a systematic relationship between percent filtration and growth (Table 15). This may be because, as pointed out earlier, the filtration method did not remove very much of the total organic carbon.

General Discussion - Oyster Growth Experiments

From what may seem to be a rather confusing collection of data generated by this series of experiments, there are a number of points that warrant consideration.

In the first place, it is obvious that oysters do not eat water, but rather, require it as a source of dissolved oxygen, to dilute and carry away wastes, and as a food containing and distributing medium. Since the food content of a given water source varies seasonally (even hourly with tidal and current changes) studies of the requirements of oysters for water can provide only a "ball park" estimate. We recognized this limitation from the beginning; but, since it has not yet been determined with any certainty exactly what oysters eat, we initially chose not to attempt to estimate the food content of a given water source by direct measurement. Our first growth experiments were intended, therefore, to more or less assay in a relative sense the capacity of a water source to support the growth of oysters. From these experiments we noted that the growth as well as the survival of oysters is quite sensitive to its food supply. We further noted that a given flow rate may support adequate growth during certain times of the year, but may yield poor growth and high mortality during periods of low food availability. For that reason we chose in our later experiments to attempt to measure various parameters (organic carbon, chlorophyll, particulate matter, etc.) that may relate to food supply. If these parameters can be related with confidence to oyster growth, they may have predictive value in considering the capacity of a water source to support growth.

It is important to keep in mind that the water filtering rate of an oyster is limited. Obviously, then, a decline in the food content of the water can be compensated for by an increase in flow only up to the point that oysters' filtering capacity becomes limiting. Increases in flow rate beyond the rate at which the oysters' maximum filtering capacity is reached do not yield increased growth.

Our results have also shown that shell growth and meat growth in oysters are two separate processes that should be considered separately. We observed increases in shell length on individual oysters that contained emaciated and watery meats.

Future Studies

Future research plans include a continued effort to monitor seasonal changes in naturally occurring organics that might serve as food for oysters (or any filter feeder). This work is in progress.

We are also continuing the work with factorial, flow x temperature, experiments to refine our estimates of water flow requirements. These experiments will use oysters of different sizes and will be timed in such a way that seasonal changes can be noted.

Additionally we are in the process of preparing a system and designing experiments to determine the feasibility of providing supplemental food (cultured algae) to the oysters in an effort to improve growth. This system will provide a controlled environment for estimating the food requirements of different sized oysters at different temperatures.

Conclusions

Very generally we can say that there is good evidence to indicate that the growth of oysters can be significantly improved by increasing temperatures up to to oyster growth, they may have predictive value in considering the capacity of a water source to support growth.

It is important to keep in mind that the water filtering rate of an oyster is limited. Obviously, then, a decline in the food content of the water can be compensated for by an increase in flow only up to the point that oysters' filtering capacity becomes limiting. Increases in flow rate beyond the rate at which the oysters' maximum filtering capacity is reached do not yield increased growth.

Our results have also shown that shell growth and meat growth in oysters are two separate processes that should be considered separately. We observed increases in shell length on individual oysters that contained emaciated and watery meats.

Future Studies

Future research plans include a continued effort to monitor seasonal changes in naturally occurring organics that might serve as food for oysters (or any filter feeder). This work is in progress.

We are also continuing the work with factorial, flow x temperature, experiments to refine our estimates of water flow requirements. These experiments will use oysters of different sizes and will be timed in such a way that seasonal changes can be noted.

Additionally we are in the process of preparing a system and designing experiments to determine the feasibility of providing supplemental food (cultured algae) to the oysters in an effort to improve growth. This system will provide a controlled environment for estimating the food requirements of different sized oysters at different temperatures.

Conclusions

Very generally we can say that there is good evidence to indicate that the growth of oysters can be significantly improved by increasing temperatures up to

$20^{\circ}C$. However, it is also evident that if these high temperatures are accompanied by decreased food availability, either because of seasonal changes in natural food or because of inadequate flow rates, the results can be disasterous. We are now in a position to estimate at least the range of flows that will be required, but these estimates must be refined to include seasonal changes in requirements before they can be considered useful. Accordingly, our present efforts are directed toward providing those refinements.

SALMON GROWTH STUDIES

Preliminary growth studies with Pink and Chum salmon were completed in the summer of 1972. The results of this work was presented in our first progress report, and will be reviewed in detail in our final report.

These preliminary studies indicated a need for additional work in two general areas, (1) disease control, and (2) the effects of different ration levels on the food consumption and growth of cultured salmon at various temperatures. A number of experiments were designed and conducted through the winter and spring of 1973 to provide additional information concerning these two problem areas.

In all of the experiments described by the following report, the fish used were Chum salmon reared from eggs taken in the fall of 1972 at the Oregon State University hatchery on Netarts Bay.

Growth Experiments

In our preliminary studies we determined the growth rates of Pink and Chum salmon juveniles at four temperatures, but at a single food ration level. Studies conducted in Newport during 1973 were designed to determine the combined effects of ration level and temperature on the food conversion and growth of Chum salmon.

Fish used in this study were vaccinated against *Vibrio* following procedures to be described later. A pooled group of about 10,000 fish was held in a number of large ambient temperature tanks at the Marine Science Center in Newport. Fish were drawn at random from these tanks for use in the following experiments.

Experiment I - May 29-July 7, 1973

Design - Fish were reared in 16 temperature-controlled tanks such that there was one tank at each combination of four temperatures (11°C, 14°C, 17°C, 20°C) and four ration levels (3%, 6%: 9% and 15% of body weight per fish per day). Following a shortacclimation period the experiment was continued for 40 days. At 10-day intervals during the experiment twenty fish from each treatment were randomly selected for weighing. The fish weighed about 1.3 g (wet) at the beginning of the experiment and had a maximum wet weight of about 2.2 g at the end.

Results - Growth rates were found generally to be higher at lower temperatures for a given ration level (Fig. 4). The difference in growth rate between fish held at 11°C and those held at 14°C is certainly not great. The significant point here is that there appeared to be no growth advantage at the higher temperature.

Figure 4 shows quite clearly the metabolic costs to the fish of increased temperature. At 20°C a ration level of 15% of dry body weight per day would have been required to just maintain the fish, that is, to prevent either gain or loss of weight. At 17°C the maintenance ration was about 10%, and it dropped to 6-7% for the two lower temperatures.

Of the four temperatures tested, the temperature yielding the best growth seems to be about 14°C for most ration levels (Fig. 5). That temperature is only slightly above ambient for Newport during the summer months.

Mortality from *Vibrio* was found to be directly related to temperature and inversely to ration (Fig. 6). These data provide a classic example of the influence of stress on disease incidence among cultured animals. In this case stress, as inadequate ration, excessively high temperature, or particularly as a combination of the two, produced high mortalities due to *Vibrio*.

Food conversion efficiency (a measure of the percentage of food consumed appearing as an increase in weight) was found to be directly related to ration level and inversely related to temperature. Since only the fraction of the food

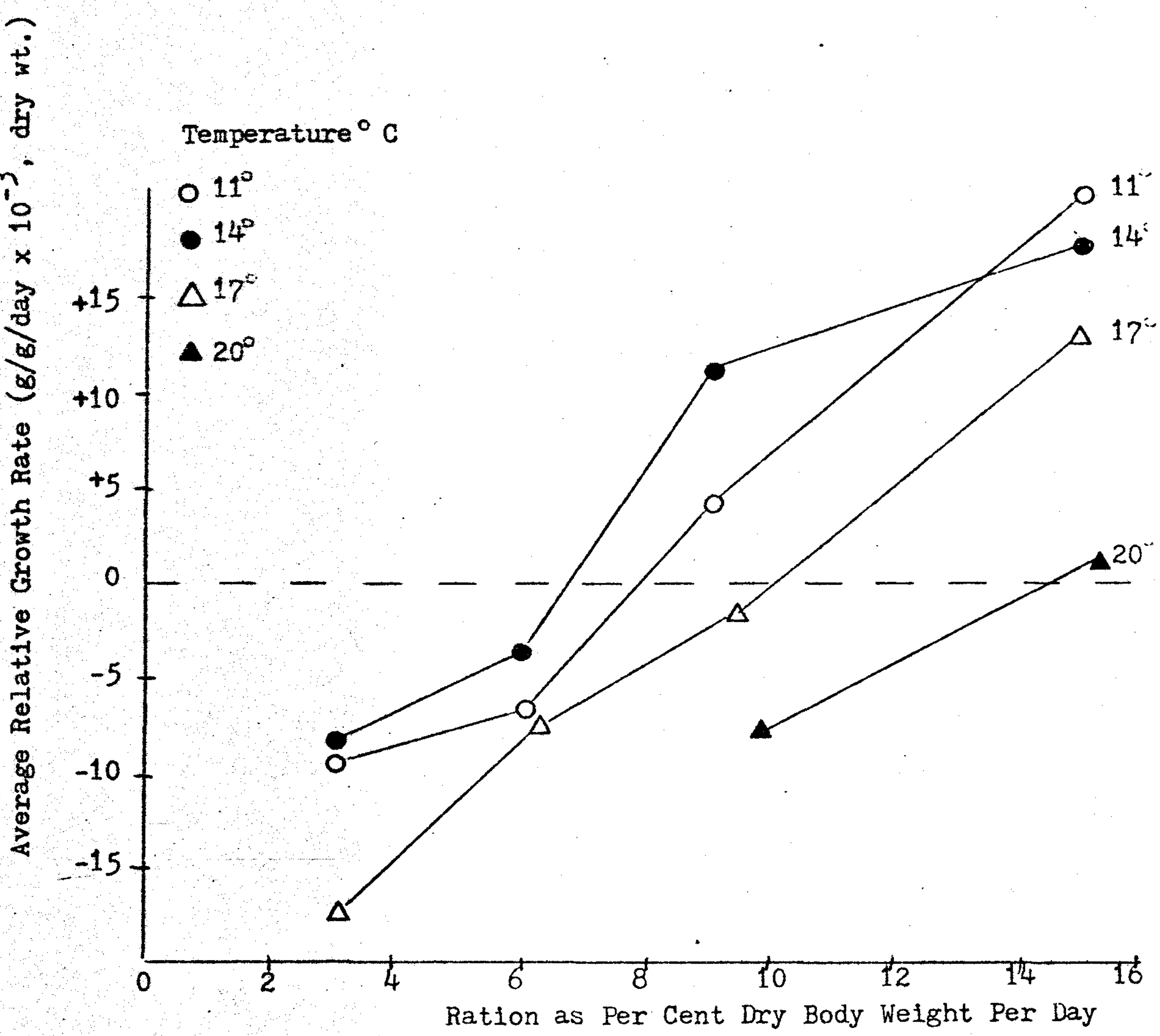

Figure 4. The relationship between ration and growth rate for Chum Salmon held at four temperatures. Experiment I, May 29- July 7,1973. The fish weighed about 1.3g at the begining of the experiment and about 2.2g at its termination.

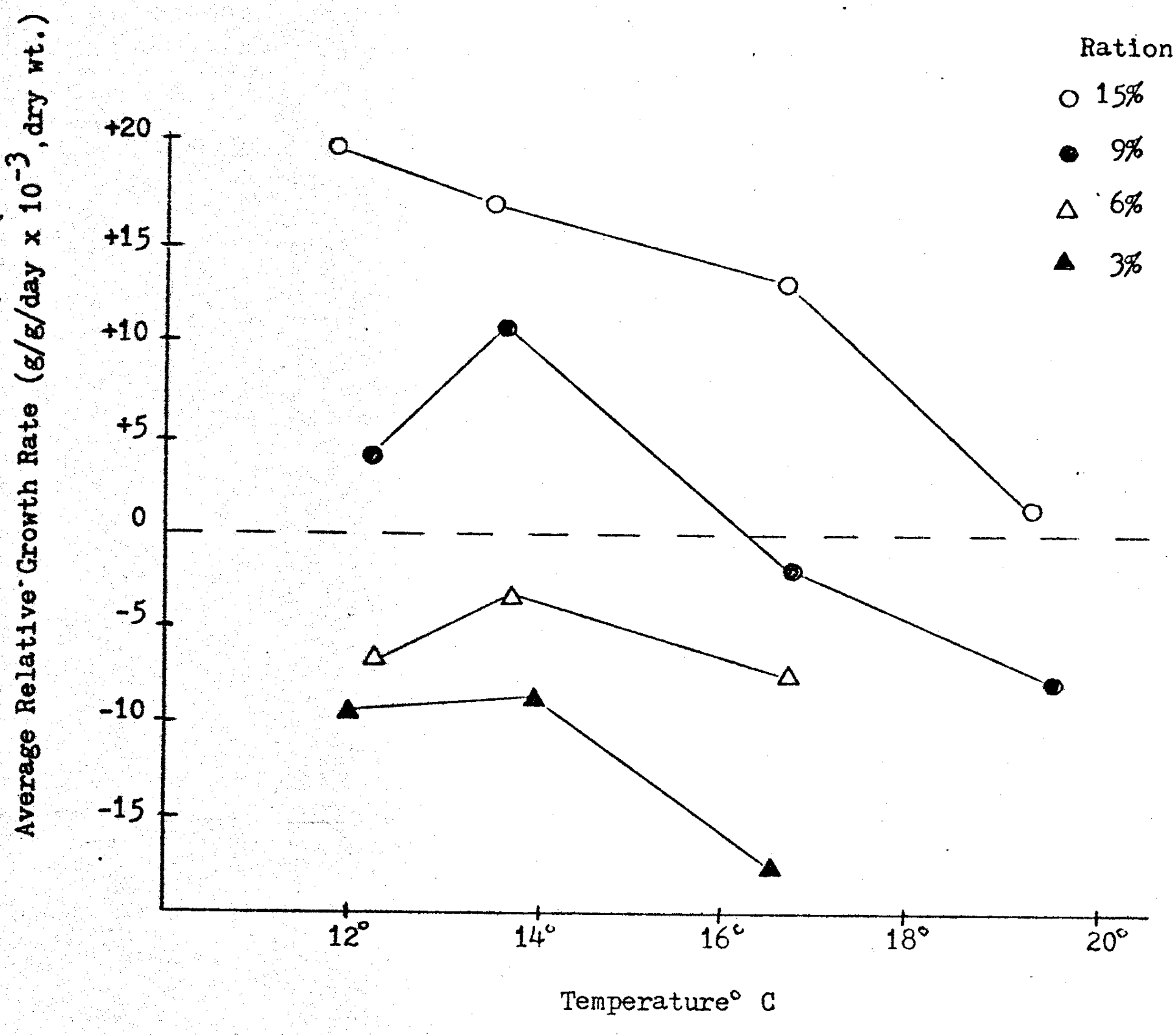

Figure 5. The relationship between temperature and growth rate for Chum Salmon fed at four different ration levels (as % dry body weight/day). Experiment I, May 29- July 7, 1973.

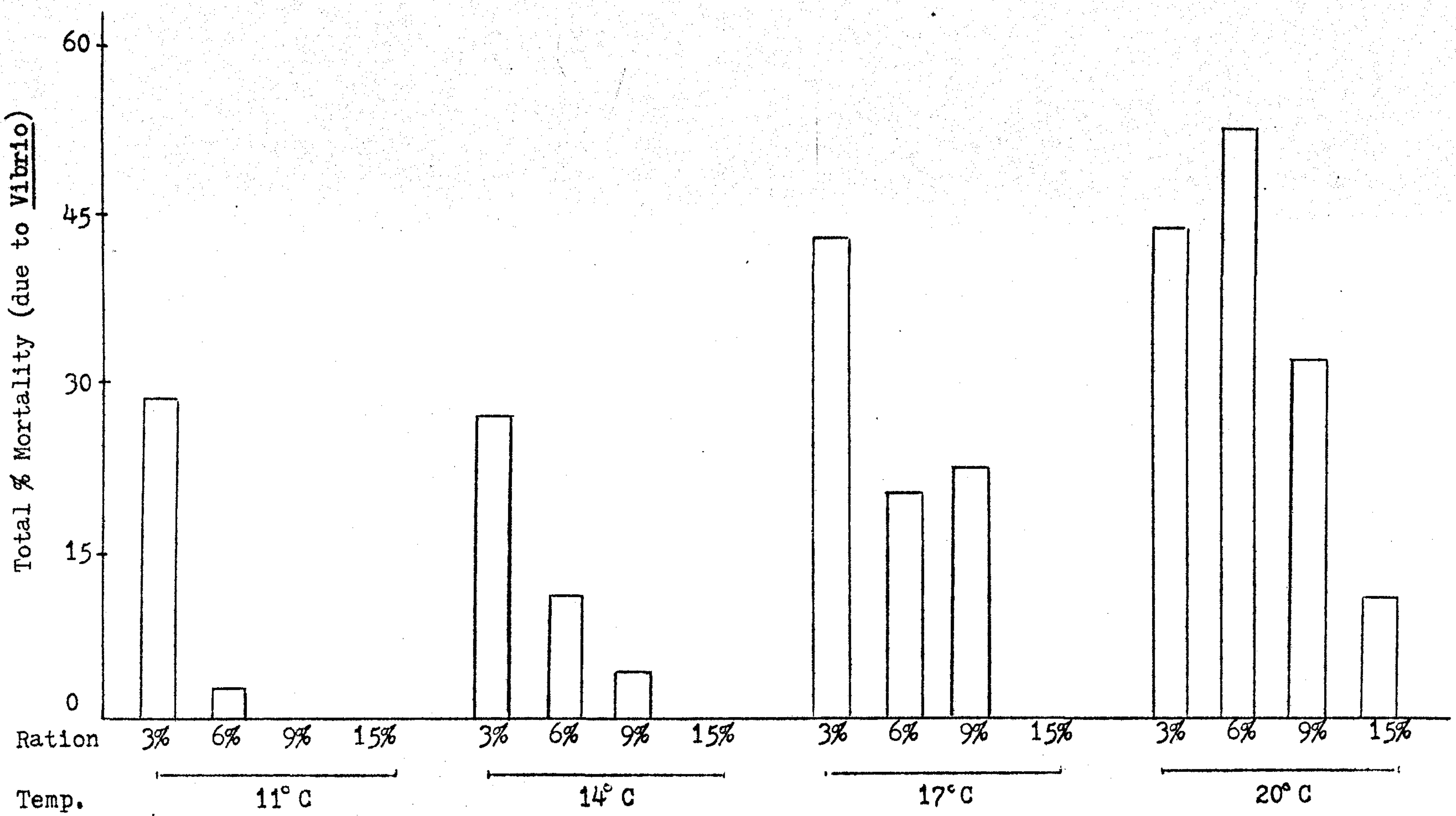

Figure 6. The combined influence of temperature and ration level (per cent of dry body weight per day) on mortality due to *Vibrio* in Chum salmon. Experiment I, May 29-July 7, 1973.

consumed that is in excess of the maintenance requirements is available for growth, the low conversion efficiencies at higher temperature reflect the high maintenance requirements at those temperatures (shown in Fig. 4). As with growth, the best food conversions were found at the highest ration (15%) and lowest temperature (11°C) and at the two higher rations (9%, 15%) at 14°C. Conversion efficiencies at 17° and 20°C were low.

Experiment II - Sept. 18-Nov. 7, 1973

Design - The second experiment of 1973 was conducted following the same general design as the first experiment. Minor changes were made in the sampling procedure and ration levels were adjusted to 3%, 8%, 13% and 18% of dry body weight per day. Fish used in the experiment averaged about 12 g wet weight at the beginning and had a maximum wet weight of about 40 g at the end.

Results - The results of Experiment II were similar in most respects to those of the first experiment.

As in the first experiment, the data from Experiment II show that the best growth was obtained from our highest ration (Fig. 7). In Experiment II, however, we found that the maximum food consumption by the fish, as a percentage of body weight, was somewhat less than Experiment I. We also found that the maintenance ration as % of body weight (ration permitting zero weight change) was less in Experiment II than in Experiment I for all temperatures. These differences in consumption and maintenance are attributable to the larger size of the fish used in the second experiment. It is generally true that fish consume and require a lower fraction of their body weight in food as they become larger.

The best growth was recorded at the higher ration levels and at about 14°C (Fig. 8). The growth curves for the two higher ration levels are quite similar

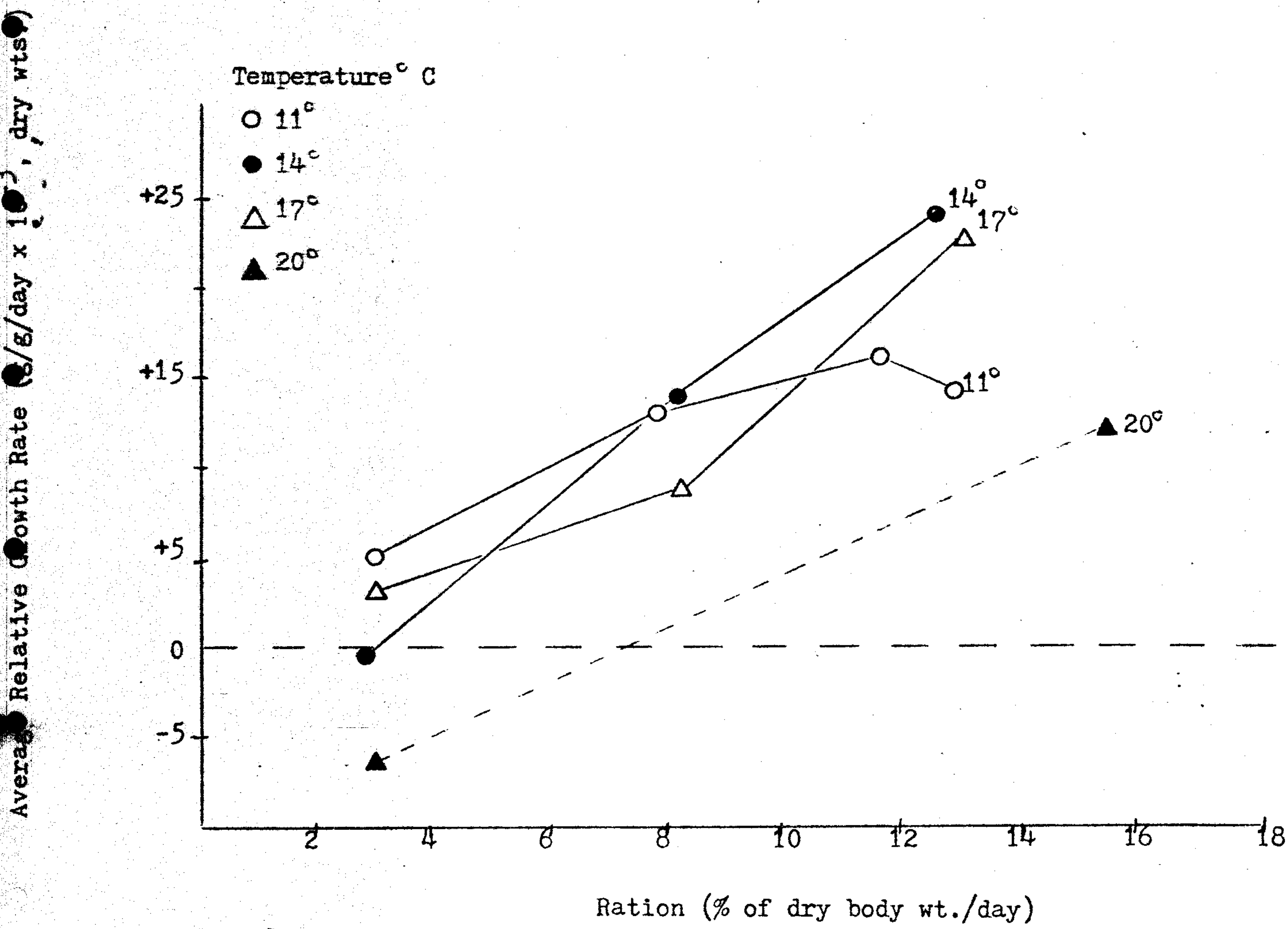

Figure 7. The relationship between ration level and growth rate for Chum Salmon held at four different temperatures. Experiment II, Sept.18-Nov. 7, 1973.

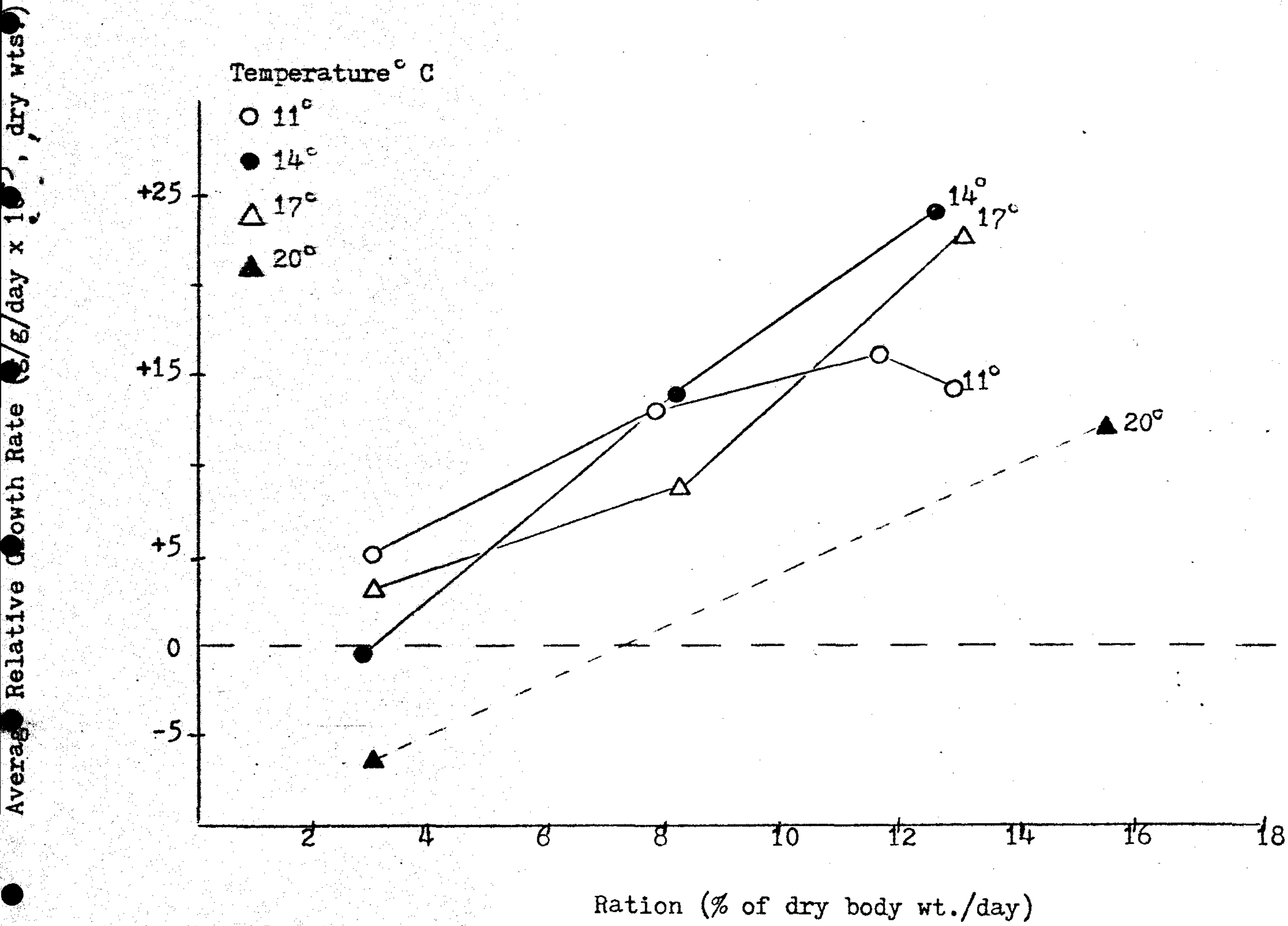

Figure 7. The relationship between ration level and growth rate for Chum Salmon held at four different temperatures. Experiment II, Sept.18-Nov. 7, 1973.

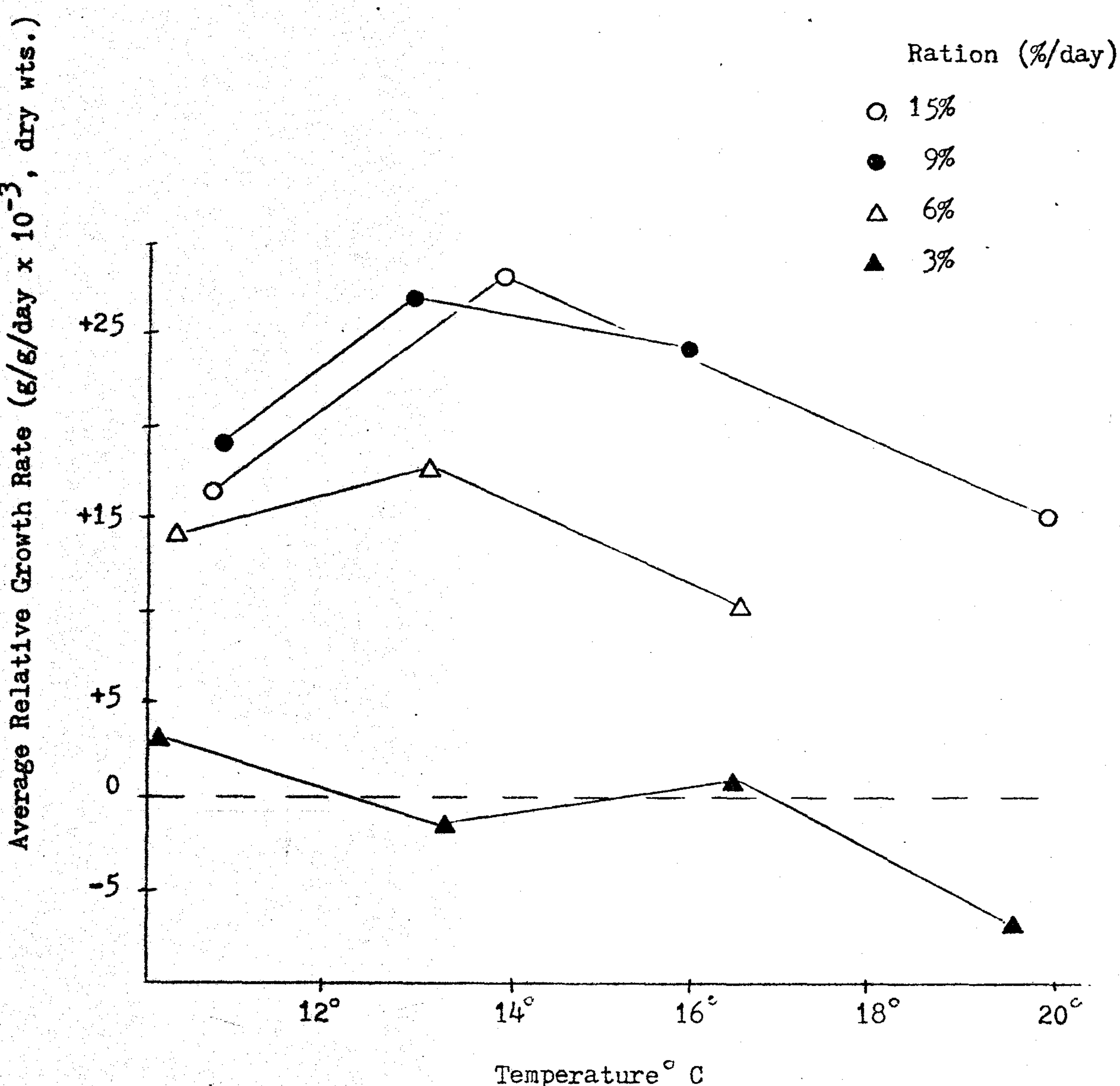

Figure 8. The relationship between temperature and growth rate for Chum Salmon fed at four different ration levels. Experiment II, Sept. 18-Nov. 7, 1973.

(Fig. 8). This is because the fish never actually consumed more than about 15% of their body weight. So that, on the basis of food consumed, the two higher ration levels (nominally, 13% and 18%), were nearly identical.

Mortalities in Experiment II were generally higher at the higher temperatures totalling 6%, 23%, 40%, and 36% at 11°, 14°, 17° and 20°C respectively. Unlike Experiment I, mortalities did not show a clear relationship with ration level in this experiment. This may be because even the lower rations were in excess of maintenance for all but the higher temperature groups (compare Figs. 4 and 7) so that low ration was a less significant stress factor in Experiment II than in Experiment I.

Disease Control

Disease control efforts during this series of experiments were concerned basically with (1) identifying the types and extent of disease problems that we might encounter, and (2) preliminary efforts to control disease.

Bacterial Kidney Disease

In our earlier work we encountered a serious problem with bacterial kidney disease. This type of kidney disease is caused by fresh water bacteria (*Corynebacterium sp.*) and has no effective treatment. The disease is chronic but can cause mortalities at elevated temperatures.

Since the disease is of fresh water origin, we theorized that it could be avoided by keeping the fish in a disease-free environment during their short fresh water period.

To test the hypothesis we split a group of chum eggs into two experimental lots, one of which was incubated following standard hatchery procedures using untreated water from Whiskey Creek, while the other was "sterile incubated". Sterile incubation consisted of the following treatments: 1) sterilization of the eggs with a bath of Wescodyne, 2) sterilization of the incubators with chlorine prior to use, and most importantly 3) continuous sterilization of the water supply (de-chlorinated city water) with ultra-violet light.

After these fish hatched and had "buttoned-up" they were moved to salt water rearing tanks at the Marine Science Center in Newport. The groups were kept separate and had subgroups at ambient ($52^{O}F$) and elevated $62^{O}F$) temperatures.

The results of the study were evaluated on the basis of the comparative growth and mortality of the groups, and on examination of fish for signs of disease and disease agents.

Since the experiment was compounded with an experimental vaccination program to control Vibriosis, the results will be discussed following discussion of the vaccination experiment.

Vibrio

Vibriosis, caused primarily by the marine bacterium *Vibrio angiularum*, was known to be a serious problem in salt water fish culture. We had not had real problems from *Vibrio* before 1973, but the experiences of others suggested that we should expect difficulties as we scaled-up our work in Newport.

In an attempt to minimize expected problems from *Vibrio* we carried out an experimental vaccination program. The work was done primarily by Dr. John Fryer and Mr. Dave Ransom of O.S.U.'s Microbiology Department. Vaccination consisted of feeding the fish killed bacterial cells mixed in with prepared fish food. The vaccine was, in this case, mixed with the starter mash and fed to the fish as soon as they started to feed. All of the fish intended for use in the growth studies were vaccinated. Sub-groups from the kidney-disease experiment (previously described) were also vaccinated. The final design of that experiment is as shown in Figure 9.

Results

High mortalities were recorded among all of the experimental groups shown in Figure 9. In fact, essentially all of the fish used in that aspect of the disease work died before the end of the summer. Vibrio was the only pathogen isolated from these fish.

Since no Corynebacteria were found and because none of the mortalities are attributable to kidney disease, it is impossible to evaluate the effectiveness of the sterile rearing procedure. Further, since the mortalities among even the vaccinated fish in this experiment eventually amounted to 100%, it must be said that the vaccination provided at best only limited protection from Vibrio. However, the sequence in which total mortality occurred (Fig. 9) indicates to us that the treatments may have had some effect on the fishes' susceptibility to Vibrio.

Notice (in Fig. 9) that the unvaccinated fish held at 17°C were the first two groups to show 100% mortality. Then, consider the four groups of fish held at 11°C as two pairs, each of which contained a vaccinated and an unvaccinated group. Notice that, as a pair, the sterile incubated group survived longer than the unsterile group, and within each pair the vaccinated group showed better survival than the unvaccinated group.

Certainly this experiment does not establish conclusively that vaccination affords protection against Vibrio. That was not its objective. But, it does