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REPORT ON

FACTORS AFFECTING GROWTH OF THE SCALES OF SALMON (SALMO SALAR)

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FACTORS AFFECTING GROWTH OF THE SCALES OF SALMON (*SALMO SALAR*)

by

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INTRODUCTION

At the beginning of the present century Hoffbauer (1899) described how the age of a carp might be determined from its scales. This was a valuable contribution to fishery work and since his time considerable literature has accumulated on the subject. No attempt will be made here to discuss the literature on the use of the scales of fishes in age and growth determinations since excellent reviews have been presented by Lee (1920), Graham (1928) and Van Oosten (1929). In the case of the Atlantic salmon, however, Johnston (1905) was the first to show that the scales recorded the age of the fish. He examined the scales of hatchery fish and found the known age and the age as read from the scales in perfect agreement. By tagging smolts in 1905 and studying the scales at subsequent recapture Johnston (1906, 07, 08) further demonstrated that the number of years spent in the sea is recorded on the scales. Since these investigations it has been generally accepted that the ages of salmon can be interpreted from the scales. The scale method has been used extensively on salmon in English and Scottish rivers; it has also been applied to salmon on this side of the Atlantic.

Little or no mention has been made in salmon literature of any difficulty in distinguishing annual from accessory checks or the factors involved in the formation of either. During investigations of salmon from the Miramichi and St. John rivers, New Brunswick, some doubt was entertained as to the interpretation of some of the checks especially in the fresh-water portion of the scale. Futhermore examination of the scales of salmon retained for 2+ years in the St. John Hatchery revealed the presence of checks of doubtful interpretation. Gray and Setna (1931) have found that Salmo irideus fed with abundant food form on a proportion of their seales abnormally wide rings even during the winter months; the variations in temperature were from 13.3° in July to 6.1°C in February. On the other hand Cutler (1918) concluded from experiments on Plaice and Flounders that the winter and summer bands of the scale are produced by temperature changes only, and that the amount of food which the fish consumes does not affect the production of summer and winter bands. Due to the absence of any such knowledge concerning the growth of salmon scales, experiments were designed to determine the effect of food, temperature and other factors on the growth of the scales, and the relation between scale and body growth under different temperature and food conditions. Particular attention has been paid to the different types of chedks produced on the scale by changes in environmental conditions to see to what extent they can be distinguished from the annual checks.

MATERIAL AND METHODS

Practically all of the fish were obtained from hatcheries. Salmon fry were received from the St. John Hatchery but were not used in any of the experiments until they were 1 + 2 + year-old parr. Fry were also brought from the Florenceville Hatchery in the fall of 1934 and used immediately in some of the experiments. Parr and smolts (2+ year-old) were transferred from the St. John Hatchery in the spring of 1936 and used that summer in some of the experiments. Outside of these hatchery sources the material consisted of only two smolts from the Miramichi River and one grilse from St. John Harbour.

The experimental troughs were made of wood and were coated with Braco, an asphalt mixture, on the inside. The inside dimensions of the troughs were: length 48", width 14", and depth 8.5". The depth of the water in each trough was only 5" making a total volume of 3360 cubic inches or 12.1 imperial gallons. Most of the experiments were carried out in McNichol's field about half a mile from the Biological Station at St. Andrews. The source of water was a spring on the side of a hill, the troughs being arranged in a double row in the open field below the spring (fig. 1-2). The troughs next the spring and the most distant troughs were protected from the direct rays of the sun by tar-paper shades while some of the intervening troughs were left uncovered. In this way low temperatures in the troughs next the spring and higher temperatures in the most distant troughs were procured. When fish were carried over winter, the arrangement was reversed and all the troughs crowded together near the spring and a fairly snug shack built over them. The salt water experiments (fig. 3) were carried out in the basement of the Station the source of water being the estuary of the St. Croix River. In this case the water was heated by means of an oil jacket-heater and the low temperature was mainly that of the river water which was cooled slightly by passing through a brine-cooler.

The food of the fry consisted mainly of straight beef liver but occasionally a mixture of beef liver, lactalbunim, dried buttermilk and salmon egg meal. The parr and smolts were fed on sliced herring. Herring of sardine size (about 5" in length) were cut into transverse slices about 1/8" thick and weighing approximately 1 gram. These whole slices were fed to the larger parr and smolts while the smaller parr were fed on half-slices.

Fig. 1. Upper section of experimental set-up at McNichol's Spring.

Fig. 2. Lower section of experimental set-up at McNichol's Spring.

Fig. 3. Experimental set-up in the basement of the Biological Station, St. Andrews, N.B.

The lengths of the fish were measured in millimeters from the anterior and of the snout to the posterior end of the middle ray of the caudal fin. Lengths were also taken to the tips of the caudal fin but in some cases these tips were sufficiently worn at the end of the experiment to render these measurements useless so they have not been used at all in these experiments. Furthermore, such measurements are not desirable where any degree of accuracy is needed for they depend too much on the degree to which the lobes of the caudal fin are spread. The fish were weighed on a torsion balance and the weights measured to the nearest half gram. The fish were weighed alive in water by previously balancing bricks on one pan against container and water on the other pan. A round tin container (10" diameter, 7" depth) was used with a 3" flange at the top to prevent loss of water when the fish was dropped in to be weighed.

In every case a sample of about 50 scales was removed from the fish at the beginning and at the end of the experiment while in some cases a sample was also removed during the experiment; the latter procedure was necessary in scale-check experiments to determine when the checks were formed. Scale samples were taken mid-way between the lateral line and the dorsal fin either on the right or left side of the fish and in line with the anterior or posterior base of the dorsal fin. Some of the scales were mounted in a glycerine waterglass mixture (5 to 6) but this was not very satisfactory because the waterglass crystallized and turned white first around the edge of the coverglass but in time under the coverglass also. For this reason De Faure's fluid was tried and proved very satisfactory. The formula for this fluid is given by Guyer (1936) in Animal Micrology. The small scales were examined and measured with a compound microscope fitted with an ocular micrometer while the large scales were measured with a Leitz-Edinger projector.

Considerable difficulty was encountered in handling the live fish to take scale samples and measurements. The first method attempted was to put the fish in a bag of cheesecloth or marquisette (no. 5) which had a round stick on each side at the open end of the bag; the cheesecloth was then rolled around these two sticks until the fish could be held firmly. The cheesecloth was then cut near both ends of the fish so the length could be measured and also near the dorsal fin so a sample of scales could be taken. As will be realized this is an awkward and tedious method as well as subjecting the fish to rather rough handling. The other method used was that of anaesthetizing the fish in an ether-water solution and this method proved very satisfactory.

The procedure used in administering the ether was as follows: Just enough water was put in a tin container to sufficiently cover the fish and allow for freedom of movement. A round container was used with a diameter of 13" and a depth of 14". The fish was then put in this container and a small quantity of ether added at intervals of about 5 minutes until the fish started to turn over on its side. It would swim around several minutes rolling from one side to the other and would shortly settle to the bottom and remain motionless except for breathing. It was then removed and the necessary operations performed. The time required in the anaesthetic before it could be handled readily was between 20 and 30 minutes. When placed back in fresh water again it would come out of the anaesthetic immediately. This method was considered better than placing the fish in a previously mixed solution of ether for there was no danger of it getting too much of the anaesthetic.

A number of tests were conducted on the time required for anaesthesia in various concentrations. The test for anaesthesia was to see if the fish, when taken out of the solution, would lie on the hand for 20 seconds without any or much movement. Quite often the fish might gulp or move its tail a little but these were not considered as any effort to escape. The results are given in table 1.

Table 1. Time required to Anaesthetize Salmon Parr in Various Concentrations of Ether.

Fish No.	Length mm.	Weight grams	Temp. °C	Ether concentration %	Solution	Time required for anaesthesia
W 4	176	63.5	8.8	0.3	Fresh	Not even on sid in 45 minutes
W.2	163	46.0	9.4	0.7	Fresh	No anaesthesia in 52 minutes
W 8	189	71.0	914	0.8	Fresh	43 minutes
W 5	189	74.0	10.6	0.8	W.8 (mixed 62')	25 minutes,40s
W 3	172	54.0	9.6	1.0	Fresh	19 min.45 sec.
W 1	191	71.5	11.8	1.0	W 3 (mixed 37')	3 min. 45 sec.

Table 1. (continued)

Fish No.	Length mm.	Weight grams	Temp. °C	Ether concentration %	Solution	Time required for anaesthesia
W 12	171	58.5	15.7	1.0	Fresh	17 min. 20 sec.
W 10	164	50.5	16.6	1.0	W 12 (mixed 45')	8 min. 40 sec.
W 11	185	65.0	8.1	1.0	Fresh	18 min. 20 sec.
W 9	161	50.0	9.6	1.0	W.11 (mixed 88')	4 min. 20 sec.
W 7	180	79.0	9.9	1.0	W.11 (mixed 80')	5 min.

In each test the quantity of water was the same, namely 6 litres, to which was added 20, 40, 50 or 60 cc. of ether. The 0.3 per cent solution was tried on W 4 fish and although the fish turned over on its side several times it soon righted itself; even after 45 minutes in the solution it was still swimming around in this fashion. So a 0.7 percent solution was tried on W 2 fish. It swam around on its side for some time and was left in the solution for 52 minutes but even then it could not be held out for 20 seconds without movement. In the 0.8 per cent solution, however, W 8 fish was anaesthetized in 43 minutes, and in the same solution an hour later W 5 fish was anaesthetized in 26 minutes, the difference in time, of course, being due to the fact that the ether was thoroughly dissolved when W 5 fish was put in the solution. In the 1.0 per cent solution the time required for anaesthēsia by W 12, W 11, and W 3 fish was 17, 18, and 20 minutes respectively. When other fish were put in these same solutions 37 to 48 minutes later the time required for anaesthēsia was only between 4 and 9 minutes. The 1.0 per cent solution would, therefore, be the most suitable concentration to use on parr between 50 and 79 grams in weight and at temperatures from 8 to 16°C.

FOOD TEMPERATURE EXPERIMENTS

Experiments in Varying the Food to Produce Checks on the Scales.

(a) Experiment W 5

The experiment was carried out on a 2+ yeaf-old parr from the St. John Hatchery. During the first 48 days of the experiment the fish was ration fed, being given either 1 or 2 half slices of herring each day. For the last 68 days of the experiment it was fed all it wished to eat. The daily food and temperatures are plotted in fig. 4. The daily food consumed during the ration-fed period was 1.6 half-slices of herring and the mean temperature was 12.2°C. The daily food consumption in the well-fed period was 5.1 half-slices of herring and the mean temperature was 12.6°C. The sex of the fish was female.

The length of the fish on June 16 was 149 mm. The length increment during the ration-fed period was 8.1 per cent and during the well-fed period 17.4 per cent. The weight on June 17 was 32.5 grams. The weight increments were: ration-fed period, 16.9 per cent; and well-fed period 94.7 per cent.

Scale Results.

Scales were removed at the beginning of the experiment, at the end of the ration-fed period, and at the end of the experiment (fig. 5). Scales removed at the beginning of the experiment had 2 complete years of growth plus 4 or 5 ridges of summer growth with a transference check at the edge or 1 ridge from the edge. There were 5 ridges added to the scale during the ration-fed period, the first two being narrow and the last 3 somewhat wider. During the well-fed period there were 7 more ridges added to the scale. The first one was very close to the last ridge of the ration-fed period, the last ridge being left incomplete when the fish was shifted from the ration-fed diet to a well-fed diet. The succeeding 4 ridges are somewhat wider than the ridges formed during the ration-fed period but the last 2 ridges are not quite so wide. In general then the ration-feeding produced slightly narrower ridges than unlimited feeding and the sudden change from one to the other left a check on the scale. The check appears to be formed by the suddenly increased growth rate initiating entirely new scale growth in place of completing the former ridges.

Fig. 4. Daily temperature and food-consumption in Experiment W 5.

Fig. 5. Experiment W 5: Scale showing effect of food on growth; TC - transference check; RF - ration-fed; WF - well-fed. X 21

(b) Experiment S 3

From June 3 to June 6, 1934, a number of migrating smolts were netted in the upper part of the estuary of the Miramichi river at Strathadam. They were transferred to St. Andrews on June 9. Later on during the summer the fish used in this experiment was transferred to salt water. The salinity was changed slowly but it was found later that this precaution was unnecessary. The procedure followed in this experiment was to give the fish very little to eat from September 27, 1934 to August 9, 1935, and to give it all it wished to eat from August 9 to November 18. No attempt was made to control the temperature.

Growth, Feeding and Temperature.

The daily temperature and food records are shown in fig. 6. The percentage weight increments are given in table 2 (also shown in fig. 6) for approximately monthly periods, the periods considerably more or less than a month being marked off from the others. The food consisted of shrimp from September 27 to December 20, 1934; beef liver from December 21, 1934 to July 8, 1935; and whole slices of herring from July 9 to November 18. The daily ration of shrimp was 1 to 2 shrimp, of liver about a half cubic inch, and of herring 4 or 5 slices. The fish was observed to feed regularly at all times except from January 18 to March 15. During this time it was seen feeding only on two occasions. The limiting factor was the temperature which varied from zero to 1 degree centigrade. Even at this temperature, however, the fish apparently did some feeding for excreta were observed in the trough, and from February 9 to March 9 it increased in weight 1.2 per cent. When the temperature was between 1 and 9°C (March 16 to June 10) the monthly weight increases were between 2 and 3 per cent. But from June 10 to July 9 the temperature rose from 9 to 12°C and evidently the basal metabolism increased to such an extent that the fish made no increase in weight. Growth was somewhat better on a herring ration than on a liver ration for from July 9 to August 9 the weight increase was 14.3 per cent. After August 9 the fish was well-fed, the food consumption showed an upward trend in spite of a falling temperature, and the weight increased considerably.

The length of the ration-fed period was 316 days and the well-fed period 101 days. The increase in weight during the ration-fed period was only 49.5 per cent and during the wöll-fed period 206.6 per cent. The length increase was 18.6 per cent in the ration-fed period and 33.6 per cent in the well-fed period.

Table 2. Percentage Weight Increments (S 3)

Periods	Weight Increments %
Oct. 23 - Nov. 23	1.5
Nov. 23/34 - Feb. 8/35	-5.6
Feb. 9 - Mar. 9	1.2
Mar. 9 - Apr. 11	3.1
Apr. 11 - May 8	2.6
May 8 - June 10	2.6
June 10 - July 9	0.0
July 9 - Aug. 9	14.3
Aug. 9 - Aug. 30	32.8
Aug. 30 - Sept. 30	56.0
Sept. 30 - Nov. 1	39.8
Nov. 1 - Nov. 18	5.8

Scale Results

Scales were removed from the fish at the beginning of the experiment, September 27, 1934; at the beginning of the wöll-fed period August 9, 1935; and at the end of the experiment, November

18, 1935. By comparing these scales the amount of scale growth during the experiment was determined. This is shown in Fig. 7, on a scale removed at the end of the experiment. Succeeding the river growth there are about 19 wide ridges representing the summer growth of 1934 previous to September 27. Then follow about 8 narrow ridges representing the growth from September 27, 1934, to August 9, 1935; i.e. during the ration-fed period. This band of narrow ridges forms a very definite check on the scale. From this check to the edge of the scale there are 10 wide ridges representing the growth during the well-fed period from August 9 to November 18. Some of the ridges in this food check are incomplete at the sides while quite a number of them extend right down the sides of the scale. The check as a whole resembles a sea winter check almost perfectly; It differs from a river winter check in the extent of growth.

Fig. 6. Daily temperature and food-consumption in Experiment S 3.

Fig. 7. Experiment S 3; scale showing effect of food on growth; RF - ration-fed; WF - well-fed. X 18.

(c) Experiment W 6

In this experiment a 2+ year-old parr from the St. John Hatchery was well-fed for 48 days and then ration-fed for 60days. The daily temperature and feeding records are shown in fig. 8. The daily food consumption in the well-fed period was 4.9 half-slices of herring and the mean temperature 12.4°C. In the ration-fed period the daily food consumption was 1.2 half-slices of herring and the mean temperature was 12.8°C. It should be noted that the daily ration was 2 half-slices of herring and that, during the latter part of the experiment, the fish would not eat more than

1 half-slice a day and some days refused to eat atall. The sexual condition of the fish is perhaps responsible as it was a mature male.

The length on June 16 was 130 mm., the length increments being 16.9 per cent for the well-fed period and 4.6 per cent for the ration-fed period. The weight on June 17 was 22.0 grams; the weight increment was 79.5 per cent for the well-fed period and 19.0 per cent for the ration-fed period.

Scale Results.

Scale samples were taken at the beginning of the experiment, at the end of the well-fed period, and at the end of the experiment. Fig. 9 represents a scale removed at the end of the experiment. It shows two complete years of growth, a transference check formed when the fish was moved from St. John to St. Andrews, five wide ridges laid down during the well-fed period and two narrow ridges formed during the ration-fed period.

Fig. 8. Daily temperature and food-consumption in experiment W 6.

Fig. 9. Experiment W 6; scale showing effect of food on growth. TC - transference check; WF - well-fed; RF - ration-fed. X 21

(d) Experiment W 8

In this experiment the fish was well-fed for the first 34 days, ration-fed during the following 33 days, and well-fed during the final 49 days. The daily temperatures and food are plotted in fig. 10. In the initial well-fed period the mean daily food-consumption was 7.8 half-slices of herring and the mean temperature was 11.5°C; in the ration-fed period the fish was given only 2 half-slices each day and the mean temperature was 14.3°C; in the final well-fed period the mean daily food-consumption was 4.2 half-slices of herring and the mean temperature was 12.2°C.

This fish was an immature female and the feeding in the final period was considerably better than that of the mature males; it was, of course, affected by the dropping temperature.

The weight of the fish on Jule 17 was 24.0 grams. The weight increments for the various food periods are as follows: initial well-fed period, 72.9 per cent; ration-fed period, 14.5 per cent; and the final well-fed period, 49.5 per cent. The length on June 16 was 137 mm., the length increment during the first two periods was 24.8 per cent and during the final well-fed period 10.5 per cent.

Scale Results.

Scales were removed at the beginning of the experiment, at the end of the ration-fed period, and at the end of the experiment so the growth during each of the periods was easily determined (fig. 11). Scales at the beginning of the experiment had a transference check at the edge so in scales removed later this check marks the beginning of the experiment. Of the ridges laid down during the experiment the first five formed during the initial well-fed period were very wide; the next five ridges formed during the ration-fed period were fairly narrow and some were incomplete at the sides; the last five ridges formed during the final well-fed period were wide again except the ridge at the edge of the scale was quite narrow. Thus the poor feeding during the ration-fed period produced a band of closely spaced, incompl ete ridges resembling a winter check fairly closely.

Fig. 10. Daily temperature and food-consumption in experiment W 8.

Fig. 11. Experiment W 8; scale showing effect of food on growth; TC - transference check; WF - well-fed; RF - ration-fed. X 21.

(e) Experiment W 7

In this experiment a 2+ year-old parr from the St. John Hatchery was well-fed for 34 days, then ration-fed for 33 days, and finally well-fed for 49 days. The daily food and temperatures are plotted in fig. 12. In the initial well-fed period the daily food consumed was 7.6 half-slices of herring and the mean temperature was 11.4°C; during the ration-fed period it was given 2 half-slices per day and the mean temperature was 14.1°C; during the final well-fed period the daily food consumption was 3.1 half-slices of herring and the mean temperature was 12.1°C. The fish was a mature male which partially explains the poor feeding in the final well-fed period.

The weight of the fish on June 17 was 40.0 grams. The weight increments for the various periods were: initial well-fed period, 47.5 per cent; ration-fed period, 15.3 per cent; final well-fed period, 16.2 per cent. The length on June 16 was 155 mm. and increased in length 16.1 per cent during the full time of the experiment.

Scale Results.

Scales were removed only at the beginning and at the end of the experiment. Scales at the beginning had 2 complete years of growth and 3-4 summer ridges with a transference check at the edge of the scale. The additional growth during the experiment consisted of 7-8 ridges, the first 4 being wide and the last 3-4 being narrow. That is, there were 4 wide ridges laid down during the initial well-fed period and 3-4 narrow ridges during the remaining ration and well-fed periods, there being no definite distinction between the widths of the ridges in the last two periods even though the feeding was slightly better in the last period.

Fig. 12. Daily temperature and food-consumption in experiment W 7.

(f) Experiment F 7

The purpose of the experiment was to determine the effect of a variation in food supply on the growth of the scale. The fish used was a 2 + year old smolt obtained from the St. John Hatchery on May 20, 1936. It was retained in fresh water until the beginning of the experiment on June 25, 1936. It was then transferred directly to a salt water trough in the laboratory basement.

The temperature was kept fairly constant during the whole time of the experiment, namely 91 days. The food, however, wax varied. The daily temperatures and food are plott d in fig. 13 and the means given in table 3, for each of the periods. During the first 39 days the fish was allowed all it wished to eat and the daily food consumption increased as the temperature increased. During the succeeding 30 days the fish was fed a ration of 4 slices of herring per day; and for the final 22 days it was again fed all it wished to eat. The mean daily food consumption for each period was: 10.8 slices of herring for the first well-fed period, 3.8 slices for the ration-fed period, and 6.2 slices for the final well-fed period. The food-consumption is considerably lower after the ration-fed period than before. If the experiment had been continued for a longer time, perhaps the amount of food eaten would have increased. At any rate that is what happened after starvation in experiment V 2. In that instance there was a recovery period of about 18 days after which the food- consumption increased. Since the temperature was fairly constant any checks occurring on the scale should be due to food only. The greatest variation in the mean temperatures of the three periods was 0.5°C.

Lengths and weights were recorded at the beginning and completion of the experiment only. The length on June 25 was 195 mm. and on September 25 was 271 mm., an increase of 39 per cent. The weight on June 25 was 68 grams and 187.5 grams on September 25 representing an increase of 175.7 per cent.

Table 3. Food Consumption and Temperature of Experimental Feeding Periods in Experiment F 7.

Experimental conditions	Well-fed	Ration-fed	Well-fed
Length of Periods	June 25-Aug.3 39 days	Aug. 4-Sept.3 30 days	Sept.4-Sept.25 22 days
Mean Daily Temp.	11.8	12.3	12.2
Mean Daily Food	10.8	3.8	6.2

Scale Results.

The scales removed at the beginning of the experiment showed two full years of growth followed by 8 or 9 ridges of growth for the current summer. The first 4 or 5 ridges of current growth were wide while the next 3 ridges were very narrow and irregular forming a prominent check in the scale growth. In some scales this check was followed by 1 or 2 wide ridges while in others the check was right at the edge of the scale. This is a transference check which was formed after the fish had been transferred from the St. John Hatchery on May 20 to St. Andrews. The time interval from transference to the beginning of the experiment was 36 days which represents approximately the time required for such a check to be laid down.

On the scales removed at the end of the experiment this transference check formed a very good mark to indicate the subsequent growth of the scale which occurred during the running of the experiment. One of these scales is represented in fig. 14. The first 10 ridges are wide and correspond to the first well-fed period (39 days) of the experiment. The next 5 ridges are considerably narrower and correspond to the ration-fed period (30 days). The following 2 or 3 ridges are wide and correspond to the final well-fed period (22 days). The 5 narrow ridges caused by ration-feeding might be called a food check. These ridges are regular and most of them extend down the sides of the scale (in this respect the photogtaph is not as representative as it should be).

Fig. 13. Daily temperature and food-consumption in experiment F 7.

Fig. 14. Experiment F 7; scale showing effect of food on growth; TC - transference check; WF - well-fed; RF - ration-fed. X 18.

Experiments in Varying the Temperature to Produce Checks on the Scales.

(a) Experiment 2 B 7

The fish used in this experiment was obtained as a fry in 1933 from the St. John Hatchery. On October 1, 1934, it was separated from the reserve supply of fish and put in a separate trough. On May 18, 1935, it was transferred to a high temperature. On September 3, 1935, it was transferred to a low temperature. At all times it was fed all it wished to eat. Previous to July 5, 1935, it was fed on beef liver but from then on to the end of the experiment on October 31, 1935, it was fed whole slices of herring. The daily food and daily temperatures are shown in fig. 15. The general trend of the food curve follows very closely that of the temperature curve.

For the high-temperature period from June 17 to September 3 the mean daily temperature was 12.8°C. For the low-temperature period from September 3 to October 31 the mean daily temperature was 9.2°C. The mean daily food consumed during the high-temperature period was 13.3 slices of herring and during the low-temperature period only 6.2 slices of herring. The temperature evidently affected the feeding considerably. The monthly weight increases were similarly affected. They varied as follows:-July 65.1 per cent; August 82.7 per cent; September 16.6 per cent; and October 7.1 per cent. The length of the fish was measured only on September 3 and October 31, the length increasing from 287 mm. to 310 mm., i.e. an increase of 8.0 per cent during the low-temperature period.

Scale Results.

Scale samples were taken at the end of the high-temperature period on September 3 and at the end of the experiment on October 31. A scale from the latter sample is shown in fig. 16. The first 12 ridges after the last winter check are wide and represent the growth during the high-temperature period, i.e. previous to September 3. The last 3 of these ridges, however, are narrower than the preceding ones and correspond to the last two weeks of the high-temperature period when the temperature and feeding dropped considerably. The next 4 or 5 ridges at the edge of the scale are narrower than any of the preceding ridges and represent the growth during the low-temperature period from September 3 to October 31.

Fig. 15. Daily temperature and food-consumption in experiment 2B 7.

Scale Results.

Scale samples were taken at the end of the high

Fig. 16. Experiment 2B 7; scale showing effect of temperature on growth; HT - high-temperature; LT - low-temperature. X 18.

(b) Experiment W 9

A 2+year-old parr from the St. John Hatchery was kept at a high temperature for 34 days, then shifted to a low temperature for 35 days, and finally back to the high temperature for 47 days, (fig. 17). The mean temperature during the initial high-temperature period was 11.4°C and the daily food-consumption 5.1 half-slices of herring; in the low-temperature period the mean temperature was 8.8 and the daily food-consumption 2.5 half-slices; during the final high-temperature period the mean temperature was 12.0°C and the food consumption 2.2 half-slices per day. The feeding did not improve any during the final high-temperature period as one would expect which is due to the fact that the fish was a mature male.

The weight of the fish at the beginning of the experiment was 19.5 grams and the weight increments were: 43.6 per cent in the initial high-temperature period, 39.3 per cent in the low-temperature period, and 28.2 per cent in the final high-temperature period. The length of the fish at the beginning of the experiment was 125 mm. and increased 28.8 per cent during the experiment.

Scale Results.

Scales were removed only at the beginning and at the end of the experiment. Those at the beginning had 2 complete years of growth followed by 4-5 ridges of summer growth with a transference check at the edge of the scale. The additional growth during the experiment consisted of 4 wide ridges during the initial high-temperature period, 4 slightly narrower ridges during the low-temperature period, and 2-3 very narrow ridges during the final high-temperature period. Thus there were wide ridges formed in the initial high-temperature, the difference being due to better feeding in the former.

Fig. 17. Daily temperature and food-consumption in experiment W 9.

(c) Experiment W 10

The fish in this experiment was a 2+ year-old parr from the St. John Hatchery. It was kept at a high temperature for 34 days, a low temperature for 35 days, and again at a high temperature for 47 days. It was well-fed at all times (fig. 18). The mean temperature of the initial high-temperature period was 11.6°C and the daily food-consumption 5.6 half-slices of herring; the mean temperature of the low-temperature period was 8.9°C, and the daily food-consumption 2.7 half-slices; the mean temperature of the final high-temperature period was 12.1°C and the daily food-consumption 1.6 half-slices of herring. This fish was also a mature male which explains the poor feeding in the final high-temperature period.

The weight of the fish at the beginning of the experiment was 20.5 grams and the weight increments during the experiment were:- 61.0 per cent in the initial high-temperature period, 36.4 per cent in the low-temperature period, and 12.2 per cent in the final high-temperature period. The length of the fish at the beginning of the experiment was 131 mm.; it increased in length 21.4 per cent during the first two periods and 3.1 per cent during the final high-temperature period.

Scale Results

Scale samples were taken at the beginning of the experiment at the end of the low-temperature period, and at the end of the experiment. The scales at the beginning of the experiment showed 2 complete years of growth and 3-4 ridges of summer growth with a transference check at the edge of the scale. The additional growth during the experiment consisted of about 9 ridges; about the first 3 formed during the initial high-temperature period were wide; the next 3 formed during the low-temperature period were not quite so wide; and the last 3 ridges formed during final high-temperature period were very narrow.

Fig. 18. Daily temperature and food-consumption in experiment W 10.

(d) Experiment W 11

The fish in this experiment was a 2+ year-old parr from the St. John Hatchery. It was kept at a high temperature for 34 days, a low temperature for 35 days, and again at a high temperature for 47 days. At all times it was given all it wished to eat.

The daily temperatures and food are plotted in fig. 19. For the initial high-temperature period the mean temperature was 11.5°C and the daily food-consumption 6.6 half-slices of herring; for the low-temperature period the mean temperature was 9.0°C and the food-consumption 4.1 half-slices of herring per day; and for the final high-temperature period the mean temperature was 12.0°C and the food-consumption 3.2 half-slices of herring per day. The fish was a male but immature. The feeding during the final high-temperature period is somewhat better than that found in the mature males (W 9, W 10, and W 12) under similar conditions.

The weight of the fish at the beginning of the experiment was 20.5 grams. The weight increments in the various temperature periods were: 73.2 per cent in the initial high-temperature period, 36.6 per cent in the low-temperature period, and 34.0 per cent in the final high-temperature period. The length at the beginning of the experiment was 130 mm. and the increase in length was 42.3 per cent during the full time of the experiment.

Scale Results.

Samples of scales were taken from this fish only at the beginning and at the end of the experiment. Previous to the experiment the scales showed 2 complete years of growth plus 3 or 4 ridges of summer growth with a transference check at the edge of the scale. The growth during the experiment consisted of about 12 ridges. The first 3-4 ridges formed during the initial high-temperature period were quite wide. The next 3 ridges formed during the low-temperature period were only slightly narrower. The last 5 or 6 ridges formed during the final high-temperature period were much narrower expecially near the edge.

Fig. 19. Daily temperature and food-consumption in experiment W 11.

(e) Experiment W 12

The fish in this experiment was a 2+ year-old parr from the St. John Hatchery. For the first 34 days it was kept at a high temperature, for the following 35 days it was shifted to a low temperature, and for the final 47 days it was again kept at a high tempe ature. It was well-fed at all times. The food and daily temperatures are plotted in fig. 20. For the initial high-temperature period the mean temperature was 11.6°C and the daily food-consumption 8.0 half-slices of herring; during the low-temperature period the mean temperature was 9.1°C and the daily food-consumption 2.2 half-slices of herring; and for the final high-temperature period the mean temperature was 12.1°C and the mean food-consumption 1.8 half-slices of herring per day. The fish was a mature male and again the feeding is not as good as it should be during the final high-temperature period1

The weight at the beginning of the experiment was 27.5 grams. and the weight increments were: 56.4 per cent in the initial high-temperature period, and 20.9 per cent in the low-temperature period, and 12.5 per cent in the final high-temperature period. The length at the beginning of the experiment was 142 mm. It increased in length 17.6 per cent during the first two periods and 2.4 per cent during the final high-temperature period.

Scale Results.

Scales were removed from this fish on three different occasions, at the beginning of the experiment, at the end of the low-temperature period, and at the end of the experiment. Previous to the experiment the scales showed two complete years of growth plus about 4 ridges of summer growth and a transference check at the edge of the scale. The additional growth during the experiment consisted of about 4 wide ridges during the initial high-temperature period, about 3 slightly narrower ridges during the low-temperature period, and 2-3 very narrow ridges during the final high-temperature period.

Fig. 20. Daily temperature and food-consumption in experiment W 12.

(f) Experiment F 4

The purpose of this experiment was to see what effect a sudden decrease in temperature would have on the growth of the scales; The history of the fish previous to the experiment is as follows. On May 20, 1936, it was transferred from the St. John Hatchery to St. Andrews as a 2+ year-old smolt. On June 5, 1936, it was transferred from fresh water to a large salt water tank in the laboratory basement where it remained until the beginning of the experiment.

The experiment was conducted in salt water and commenced on June 19, 1936. During the first 46 days the temperature was raised gradually from around 11° to over 16°. On August 4, the temperature was lowered suddenly to a little over 12° and kept at that temperature until September 4, a total of 31 days. The fish was then shifted back suddenly to the high temperature for the succeeding 19 days. The experiment ended on September 23. The length of the experiment was 96 days and during this time the fish was fed all it could eat.

Growth, Temperature and Food

Lengths and weights were taken only at the beginning and completion of the experiment. The length on June 19 was 199 mm. and on September 23 it was 259 mm., an increase of 30.2 per cent. In weight it increased from 77 grams on June 19 to 190.5 grams on September 23, i.e. 147.4 per cent. The daily food and temperatures are plotted in fig. 21, and the mean daily food and temperature for each of the temperature periods are given in table 4. During the initial high temperature period the temperature increased steadily from 11° to over 17° while the food-consumption showed a similar increase from around 5 slices of herring per day to 21 slices per day. The average for the period was 14.1° and the average food-consumption was 10.4 slices per day. During the next period the temperature remained uniformly low around a mean of 12.4° while the food-consumption showed a sudden drop followed by a gradual decrease with a mean of 8.1 slices for the period. During the final period the temperature was uniformly high around a mean of 16.3° while the food-consumption showed only a slight increase corresponding to the increase in temperature followed by a gradual decrease with a mean of only 3.0 slices per day for the period. Although the temperatures were practically the same in the initial and final periods, the food-consumption was considerably less in the final period and it looks as if the sudden changes in temperature have adversely affected feeding. However, the fish was not in good condition at the end of the experiment.

Table 4. Food Consumption and Temperature of Experimental Temperature Periods in Experiment F 4.

Experimental conditions	High Temp.	Low Temp.	High Temp.
Length of Periods	June 19-Aug.4 46 days	Aug.4 - Sept.4 31 days	Sept.4-Sept.23 19 days
Mean Daily Temp.	14.1	12.4	16.3
Mean Daily Food	10.4	8.1	3.0

Scale Results

Scale samples were removed from the fish at the beginning of the experiment on June 19 and at the end of the experiment on September 23. The scales removed at the beginning of the experiment had a very definite check about 1 or 2 ridges from the edge of the scale. This check consists of 2 or 3 very narrow, discontinuous ridges which were laid down after the fish was transferred from St. John to St. Andrews on May 20. This transference check could easily be located on the scales removed at the end of the experiment and the new growth thereby determined (fig. 22). There were about 16 ridges formed on the scale during the course of the experiment. The first 7 or 8 ridges are wider than any of the others and correspond to the high temperature period from June 19 to August 4 when the feeding was good. During the low temperature period from August 4 to September 4 the feeding decreased considerably and only 3 or 4 narrow ridges were formed on the scale. These ridges are narrower than either the preceding or following ridges and extend down the sides of the scale. From this temperature check to the edge of the scale there are 5 or 6 fairly wide ridges representing the scale growth during the high temperature period from September 4 to September 23. These ridges are wider than the ridges formed during the low temperature period but not as wide as those formed during the initial high temperature period.

Fig. 21. Daily temperature and food-consumption in experiment F 4.

Fig. 22. Experiment F 4; scale showing effect of temperature on growth; TC - transference check; HT - high temperature, LT - low temperature. X 18.

(g) Experiment W 1.

A 2+year-old parr was used in this experiment. The temperature was varied and the fish was well-fed at all times (fig. 23) For the first 35 days from June 15 to July 20 the temperature was kept low, the mean being 7.7°C; the mean food-consumption for this period was 4.6 half-slices of herring per day. During the following 35 days from July 21 to August 24 the temperature was high, the mean being 14.0°C; the feeding accordingly increased to 7.9 half-slices of herring per day. During the final 47 days the temperature was again low, the mean being 9.1°C; and during this period the feeding decreased to 2.4 half-slices per day.

The weight on June 17 was 25.0 grams. The weight increment during the initial low temperature period was 42 per cent, during the high temperature period 62 per cent, and during the final low temperature period only 24.3 per cent. The length at the beginning of the experiment on June 15 was 140 mm. and at the end of the experiment on October 10 was 191 mm., representing an increase of 36.4 per cent during the full time of the experiment. The sex of the fish was female, immature.

Scale Results.

The scales removed at the beginning of the experiment showed 2 complete years of growth followed by 3 ridges of summer growth with a transference check (St. John to St. Andrews, May 20) at the edge of the scale. Fig. 24 represents a scale removed at the end of the experiment showing this transference check and the subsequent growth of the scale during each of the low and high temperature periods. During the initial low-temperature period there were 4 ridges formed on the scale, the first two being narrow, the third and fourth very wide. The next five ridges correspond with the high-temperature period, the first two being fairly wide and the next three fairly narrow. Apparently the former were laid down during the first two weeks of the high temperature period when the feeding was greatest and the latter during the last three weeks of this period when the feeding declined rapidly. The last three ridges on the scale are fairly wide and correspond with the final low temperature period.

In this instance then the widest ridges were laid down during the low temperature (around 8°C) and the narrowest ridges during the high temperature (around 15°C). Although the difference between the widths of the ridges was not very great it does show that a check may be formed on the scale if the feeding does not increase proportionately with the increase in temperature. The only reason that can be suggested for the decline in feeding during the high temperature is that the temperature was too high, i.e. the temperature was above the optimum feeding temperature.

Fig. 23. Daily temperature and food-consumption in experiment # 1.

Fig. 24. Experiment W 1; scale showing effect of temperature on growth; TC - transference check; LT - low temperature; HT - high temperature. X 21.

(h) Experiment W 2.

The fish used in this experiment was a 2+ year-old parr received from the St. John Hatchery May 20, 1936. The temperature was varied and the fish well-fed throughout the experiment (fig. 25) For the first 35 days from June 15 to July 20 the fish was kept at a low temperature, the mean temperature being 7.8°C and the daily food-consumption 3.0 half-slices of herring per day; during the following 35 days (July 21 - August 24) the fish was kept at a higher temperature the mean being 14.2°C and the food-consumption increased slightly to 4.6 half-slices per day; during the final 47 days of the experiment (August 25 - October 10) the fish was shifted back to a low temperature, this time the mean temperature being 9.1°C and the mean food consumption decreasing to 0.5 half-slices per day, i.e. a quarter of a slice a day which is a very small amount. The fish was a male parr and mature which perhaps is partly responsible for such poor feeding during the last period.

The weight of the fish at the beginning of the experiment on June 17 was 23.0 grams. The weight increments for the various periods were: initial low-temperature period, 28.3 per cent; high temperature period, 59.3 per cent; and the final low-temperature period, - 2.1 per cent. The length of the fish on June 15 was 134 mm. During the first two periods, namely initial low-temperature and high-temperature, it increased in length 18.7 per cent and during the final low-temperature period the increase was 2.5 per cent.

Scale Results.

Scales were removed at the beginning of the experiment, at the end of the high temperature period, and at the end of the experiment. The scales removed at the beginning of the experiment showed 2 complete years of growth and about 4 ridges of current summer growth with a transference check at the edge (transferred from St. John to St. Andrews May 20, 1936.) The scales removed at the end of the high-temperature period and at the end of the experiment were practically similar. They showed 7-8 ridges of growth formed during the experiment; the first ridge formed part of the transference check, the second ridge was fairly narrow, and the remaining ridges were fairly wide, the widths being quite uniform except the last ridge was narrower than the others. That is the widths of the ridges were practically the same during the initial low and high-temperature periods and possibly no ridges were formed during the final low-temperature period.

Fig. 25. Daily temperature and food-consumption in experiment W 2.

(i) Experiment W 3

In this experiment a 2+ year-old parr from the St. John Hatchery was fed all it wished to eat at all times but the temperature was varied (fig. 26). During the initial low-temperature period (35 days) the mean temperature was 7.8°C and the food-consumption was 4.6 half-slices of herring per day. During the succeeding high-temperature period (35 days) the mean temperature was 14.0°C and the food-consumption 5.6 half-slices per day. During the final low-temperature period (47 days) the mean temperature was 9.3°C and the food-consumption only 0.5 half-slices per day. Here also the feeding was very poor in the last period and the fish was a mature male.

The weight of this fish on June 17 was 26.0 grams. The weight increments were: initial low-temperature period, 40.4 per cent; high temperature period, 56.2 per cent; and the final low-temperature period, - 5.3 per cent. The length of the fish on June 15 was 137 mm. and the increase during the full time of the experiment was 25.5 per cent.

Scales Results.

Scales were removed at the beginning and at the end of the experiment. Scales at the beginning of the experiment had 2 complete years of growth and about 4 ridges of current summer growth with a transference check at the edge, i.e. transference check from St. John to St. Andrews on May 20, 1936. At the end of the experiment the scales had in addition about 9 ridges of new growth. The first 4 ridges were fairly wide and the last 5 ridges were somewhat narrower, the ridge at the edge of the scale being the narrowest. So the ridges laid down during the initial low temperature period were slightly wider than the ridges laid down during the high temperature period, the last narrow ridge at the edge of the scale possibly being laid down during the final low temperature period.

Fig. 26. Daily temperature and food-consumption in experiment W 3.

(j) Experiment W 4

The fish in this experiment was subjected to low and high temperatures but was well-fed at all times. The daily temperature and food are plotted in fig. 27. During the initial low-temperature period (35 days) the mean temperature was 7.9°C and the mean food-consumption 5.4 half-slices of herring per day; in the succeeding high-temperature period (35 days) the mean temperature was 14.2°C and the mean food-consumption 5.3 half-slices of herring per day; and in the final low-temperature period (47 days) the mean temperature was 9.3°C and the mean food-consumption 0.6 half-slices per day. The sex was male and mature.

The weight on June 17 was 34.0 grams. The weight increments are as follows:- initial low-temperature period, 33.8 per cent; high-temperature period, 42.9 per cent; and in the final low-temperature period, -2.3 per cent. The length on June 15 was 148 mm. It increased in length 16.9 per cent during the first two periods and 1.7 per cent in the final low-temperature period.

Scale Results.

Scales were removed at the beginning of the experiment, at the end of the high-temperature period, and at the end of the experiment. At the beginning of the experiment the scales showed 2 complete years of growth followed by 3-4 summer ridges with a transference check at the edge of the scale. The scales at the end of the high-temperature period showed an additional growth of ab ut 7 ridges, the widths being fairly uniform. The first ridge next the transference check was narrower than the others and the last two ridges (especially the last) slightly narrower than the preceding ridges. There were no ridges formed during the final low-temperature period for the scales removed at the end of the experiment were practically the same as those removed at the end of the high-temperature period. To sum up then, it might be said there was little or no change in the width of the ridges in shifting the fish from the low to the high temperature.

Fig. 27. Daily temperature and food-consumption in experiment W 4.

(k) Experiment F 8

The idea of this experiment was to find out the effect of a sudden increase in temperature on the growth of the scale. The material consisted of a 2+year-old smolt transferred from the St. John Hatchery on May 20, 1936. It was retained in fresh water until June 5 when it was transferred to an salt water tank in the basement of the laboratory to rid it of fungus. The change from fresh water to salt water was sudden but the fish showed no signs of discomfort supposedly because it was a smolt. It was kept in this tank until the beginning of the experiment. The experiment was started on June 19, 1936 and ended October 6, 1936 a total of 109 days and during the whole of this time the fish was allowed all it wished to eat. The temperature, however, was varied. During the initial 46 days from June 19 to August 4 the temperature was low; during the succeeding 31 days from August 4 to September 4 the temperature was high; and during the final 32 days from September 4 to October 6 the temperature was low again.

Growth, Temperature and Food.

Since difficulty had been experienced previously in keeping fish alive in salt water when handled too frequently, we refrained from measuring or weighing the fish during the progress of the experiment. Accordingly, only the growth for the full time of the experiment can be given. The fish increased in length from 220 mm. on June 19 to 301 mm. on October 6, a length increment of 81 mm. or 36.8 per cent. The weight increased from 95.5 grams on June 19 to 270.5 grams on October 6, a weight increment of 175 grams or 185.2 per cent. The growth, therefore, was quite considerable.

The food consisted of whole slices of herring; the food consumption per day and the daily temperatures are plotted in fig. 28. As will be seen the effect of temperature on feeding is quite marked. During the initial period both temperature and food-consumption were increasing quite regularly. The maximum feeding occurred on August 4, the first day of the high-temperature period, when the temperature was 13.8°C. During the remainder of this period the temperature was between 16 and 18° and the feeding steadily decreased. When the fish was shifted back to the low temperature, the food consumption dropped immediately to a level below either of the previous two levels. The food curve than follows fairly reg larly the trend of the temperature curve as it had done during the initial low-temperature period.

The mean daily temperature for each of the experimental temperature periods is given in table 5. together with the mean daily food-consumption for these periods. The mean daily temperatures for the initial and final low-temperature periods were practically the same, namely 11.7° and 11.9° respectively. The temperature for the high-temperature period was about 5 degrees higher, namely 16.5°. The food consumed in this period was 12.4 slices of herring per day while in the initial low-temperature period it was 11.0 and in the final low-temperature period it was 5.0 slices per day. Thus we see that the food-consumption varied with the temperature but not always in the same proportion since the temperatures in the initial and fimal period were practically the same but the food-consumption was considerably higher in the initial (11.0) than in the final period(5.0).

Table 5. Food Consumption and Temperature of Experimental Temperature periods in Experiment F 8.

Experimental Conditions	Low temp.	High Temp.	Low Temp.
Length of Periods	June 19-Aug. 4 46 days	Aug. 4-Sept.4 31 days	Sept.4-Oct.6 32 days
Mean Daily Temp.	11.7	16.5	11.9
Mean Daily Food	11.0	12.4	5.0

Scale Results.

At the beginning of the experiment on June 19, 1936, a sample of scales was removed from the left side of the fish near the dorsal fin and at the end of the experiment on October 6, 1936 a similar sample of scales was removed from the right side. The scales at the beginning of the experiment showed two winter checks plus 7-8 ridges of growth for the current year. Of the latter, the first 3-4 ridges were wide, the next 3 were narrow and 1 ridge at the edge of the scale was wide. The 3 narrow ridges form the transference check caused by the transferring of the fish on May 20 from St. John to St. Andrews, Fig. 29. represents a scale removed at the end of the experiment showing the additional growth during the experiment. There were 9 very wide ridges laid down in the initial low-temperature period and 10 narrower ridges of approximately uniform width laid down in the two following high and low temperature periods together. The last ridge, however, was narrower than the preceding ridges and the last two ridges at the edge of the scale were disconnected. The width of the ridges is evidently quite dependent on the relation between feeding and temperature. In the initial low-temperature period the ridges were wide because the feeding was good and increased with the rising temperature. When shifted to the high temperature the feeding started to drop off because the temperature was too high and consequently narrower ridges were formed in this period. When shifted back to the low temperature the feeding dropped off accordingly and the ridges formed were still narrow and approximately the same width as those of the high-temperature period.

Fig. 28. Daily temperature and food-consumption in experiment F 8.

Fig. 29. Experiment F 8; scale showing effect of temperature on growth; TC - transference check; LT - low temperature; HT - high temperature X 18.

Experiments at Various Temperatures and with Various Amounts of Food.

(a) Experiments A 5-6 B 5-6

On September 6, 1934, a supply of fry was received at St. Andrews from the Florenceville Hatchery. On October 15, 1934, 200 of these fry of approximately the same size were selected for the experiments, 50 fish being used in each experiment. The experimental conditions were as follows: A 5 and A 6 were kept at a low temperature, A 5 being ration-fed and A 6 being well-fed; B 5 and B 6 were kept at a high temperature, B 5 being ration-fed and B 6 well-fed. The experiments were carried out at McNichol's spring. The spring issuing from the side of a hill was well shaded by trees. This provided a steady, low temperature and a higher temperature was procured by holding this water back in a number of troughs exposed to the sun. The fish in all the experiments, however, were shaded from the sun. During the winter months (from December 10, 1934 to May 18, 1935) all the troughs were shifted as close as possible to the spring and a temporary house built around the entire set-up. During the winter the temperature of the water next the spring was slightly higher so fish B 5 and B 6 were kept in that position.

The mean seasonal temperatures for each of the experiments are given in table 6. A 5 and A 6 were at practically the same temperature throughout and the same may be said for B 5 and B 6. In the fall season the mean temperature was the same for A 5-6 and B 5-6, namely 8.1°C. During the winter season the mean for B 5-6 was 6.3°C and about half a degree lower for A 5-6. In the summer season there was a greater difference between the temperatures of the two sets of experiments, 9.4° for A 5-6 and 12.3 for B 5-6. It should be mentioned in this connection that it was found impossible to record the temperatures every day during the course of these experiments so the above temperatures merely indicate the change rather than show the actual differance in temperature.

Table 6. Mean seasonal temperatures (°C) in experiments A 5-6 B 5-6.

Exp't. No.	Fall Oct.15/34 Dec.10/34	Winter Dec.10/34 May 18/35	Summer May 18/35 Sept.27/35	Experimental Conditions
A 5	8.1	5.6	9.4	Low temp.; ration-fed
A 6	8.1	5q9	9.4	Low temp.; well-fed
B 5	8.1	6.3	12.3	High temp.; ration-fed
B 6	8.2	6.3	12.3	High temp.; well-fed.

The food consisted of either beef liver along or a mixture of beef liver, lactalbumin, dried buttermilk and salmon egg meal. The liver formed about half the mixture while equal parts of the other substances were mixed with it. The liver mixture was used only for a month or so in the fall. The fish were fed twice a day in the fall but only once a day during the rest of the experiment.

The amount of liver fed to or eaten by the fish was not weighed so the only record of feeding is whether the fish were seen feeding or not. The feeding in all of these experiments was certainly retarded during the winter months for fish were seen feeding only occasionally. The temperatures were the lowest in February and March, being around 5.0° in A 5, 5.5° in A 6, and 6.° in B 5 and B 6. Better feeding was noticed in April which is associated with only a slight increase in temperature of about half a degree. In May and the following summer months the feeding improved rapidly.

The fish were weighed alive in water at approximately monthly intervals with the exception of four months during the winter. The mean weights as well as the percentage increase per month for each lot of fish are given in table 7. The mean weights were almost exactly the same at the beginning of the experiment, namely 1.4 grams. In each experiment there was a slight loss in weight during the first month which might readily be expected in the ration-fed fish but in the well-fed fish it seemed strange for all the fish seemed to be feeding all right. However, it is likely due to the decreasing temperature at this time. During the five winter months from November 15, 1934 to April 25, 1935 all the fish increased in weight even though the temperature was as low as 5 and 6°C. Most of this weight was no doubt put on during March and April when the fish were observed feeding more frequently.

At the end of April A 6, B 5 and B 6 had the same weight, 2.0 grams, while A 5 weighed slightly less, 1.7 grams. During the winter months there was not enough difference in the temperatures to have much effect on growth. In May and the following summer months the effect of food and temperature is quite marked. There was a steady increase in weight in all the experiments. B 6 at the high temperature and well-fed showed the best growth during the summer months increasing from 2.0 grams at the end of April to 11.6 grams at the end of September. The next best growth was shown by A 6 at a low temperature and well-fed with an increase from 2.0 grams to 8.5 grams. Growth was considerably poorer in B 5 and A 5 which were both ration-fed. There was slightly better growth in B 5 at the high temperature, from 2.0 grams at the end of April to 5.5 grams at the end of September, while A 5 at the low temperature increased from 1.7 to 4.6 grams. In the latter case the slight difference in weight cannot be said to be due to temperature for the food was not weighed exactly.

In the well-fed experiments A 6 (low temperature) and B 6 (high temperature) the percentage increases in weight during each of the summer months show the maximum increase to be in the month of June and not in August when the temperature was highest. In B 6 the temperature in June was around 9°C, the increase in weight 56.7 per cent while in August the temperature was 12-18°C and the weight increase 33.3 per cent. In A 6 the temperature in June was around $8^{o}C$ and the weight increase 46.4 per cent while in August the temperature was $9-11^{o}C$ and the weight increase 41.2 per cent.

Table 7. Mean Weights (grams) and Monthly Weight Increments (%) for Experiments A 5-6 B 5-6.

	Low Temperature				High Temperature			
	A 5 ration-fed		A 6 Well-fed		B 5 ration-fed		B 6 well-fed	
1934-35	Mean Weight grams	Weight Increment %	Mean Weight grams	Weight Increm. %	Mean Weight grams	Weight increm. %	Mean Weight grams	Weight Incr. %
Oct. 15	1.4		1.3		1.4		1.4	
Nov. 15	1.2	-14.3	1.2	-7.7	1.3	-7.1	1.3	-7.1
Apr. 25	1.7		2.0		2.0		2.0	
May 31	2.1	23.5	2.8	40.0	2.6	30.0	3.0	50.0
June 30	2.5	19.0	4.1	46.4	2.9	11.5	4.7	56.7
July 31	3.3	32.0	5.1	24.4	3.8	31.0	7.2	53.2
Aug. 31	4.3	30.3	7.2	41.2	5.1	34.2	9.6	33.3
SEpt.25	4.6	7.0	8.5	18.1	5.5	7.8	11.6	20.8

At the beginning of these experiments a control sample of 20 fry had a mean weight of 1.5 grams and a mean length of 51. mm. to the mid-fork of the tail. The mean weights and lengths at the completion of the experiments on September 27 are given in table 8.

The fish were killed in formalin and immediately weighed and measured. The best growth (both length and weight) was obtained in B 6 at a high temperature and well-fed; the next best in A 6 at a low temperature and well-fed; considerably poorer growth in B 5 at a high temperature and ration-fed; and the poorest growth of all in A 5 at a low temperature and ration-fed. There is a significant difference in length or weight between any of the experiments except A 5 and B 5. That is in these ration-fed fish there was no significant difference between the effect of a high or low temperature on growth. The test of significance used in these cases was that the difference between the means must be greater than twice the square root of the sum of the squares of the standard errors of the means. At both high and low temperatures unlimited feeding produced better growth than ration-feeding and there was a greater difference at the high temperature. A high temperature produced better growth than a low temperature when the fish were well-fed but no significant difference when ration-fed.

The standard errors of the means show the extent of variation in the length and weights under the different temperature and food conditions. The high temperature produced a greater variation in lengths and weights than the low temperature whether the fish were well-fed or ration-fed. The unlimited feeding produced a greater variation in lengths and weights than the ration feeding at both the low and high temperaturea (one exception in the weights at the low temperature where ration-fed fish, A 5, showed greater variation than well-fed fish, A 6). It is easy to see that an unlimited food supply would produce a greater variation in sizes of fish than a limited supply of food. But a high temperature producing a greater variation than a low temperature is perhaps not so obvious. It must, though, be due to the increased activity of the fish at the high temperature. Under natural conditions in the streams there is always a competition for food. The parr occupy certain areas and cautiously guard these feeding places against intruders; When crowded together in experimental troughs they could not be observed to occupy any definite positions but were often seen darting at each other. Naturally the more active fish will intimidate the others even though they may do no bodily harm. Some of the ration-fed fish (B 5) had worn fins so they were watched expressly to see what was happening. They were observed biting at each others fins and bodies, and picking up bits of debris on the bottom of the trough and spitting it out again! A few experiments were attempted with only three fish to a trough but this was found impracticable because of the fighting resulting in actual injuries to the fish. With a larger number of fish they are not usually injured.

Table 8. Mean weights and lengths in Experiments A 5-6, B 5-6.

Experimental conditions	Exper't No.	Mean Weight grams	Mean Length (mid-fork) mm.
Low Temp.; ration-fed	A 5	4.45 ± .25	75.08 ± 1.42
Low Temp.; well-fed	A 6	8.26 ± .18	91.12 ± 1.84

Table 8 (continued)

Experimental conditions	Exper't No.	Mean Weight grams	Mean Length (mid-fork) mm.
High Temp. ration-fed	B 5	5.38 ∓ .50	78.03 ∓ 2.40
High Temp.; well-fed	B 6	11.60 ∓ 1.12	99.29 ∓ 3.01

The sexes were quite evenly distributed in the four lots of fish. The percentages of females in the various experiments were:- A 5, 54.8; A 6, 60.0; B 5, 60.0; B 6, 50.0. Of all the male fish only one was found to be mature. When the fish were opened to determine the sex the amount of fat on the viscera was noted. The ration-fed fish (A 5 and B 5) had very little fat. Of the well-fed fish A 6 at the low temperature were quite fat while B 6 at the high temperature were very fat.

(b) Experiments A 1-2, B 1-2

The fish in these experiments were obtained as fry from the St. John Hatchery on July 11, 1933. The experiments were started on June 8, 1935, and lasted until September 24, a period of 108 days. The fish at this time were 2+year-old parr. Two of the fish were kept at a low temperature, one (A 1) being ration-fed and the other (A 2) well-fed. Two other fish were kept at a higher temperature and similarly one (B 1) was ration-fed and the other (B 2) well-fed.

The mean temperature and daily food-consumption for each of the fish are given in table 9. The mean temperature for both A 1 and A 2 was 8.8°C and the high temperatures were 12.1°C for B1 and 12.0°C for B 2. A 1 at the low temperature and B 1 at the high temperature were fed only 2 half-slices of herring per day. A 2 at the low temperature and B 2 at the high temperature were fed all they wished to eat. Feeding was somewhat better at the high temperature for on the average A 2 ate only 11.5 half-slices per day while B 2 ate 17.6 per day. The daily temperatures and food-consumption for A 2 and B 2 are shown in fig. 30. In B 2 both feeding and temperature were steadily increasing previous to the middle of August and decreasing subsequently. The feeding, however, reached a maximum on August 13, when the temperature was 15.5°C, while the maximum temperature (17.3°C) was reached about a week later on August 19. Thus a maximum feeding temperature is somewhere around 15°C. In A 2 the maximum temperature was also on August 19 but was only 10.°C and the maximum feeding occurred about the same time. The subsequent decrease in temperature was less than a degree but was sufficient to start a decline in feeding. It seems more than likely that maximum and minimum daily temperatures would be more useful in showing the relationship between feeding and temperature than the mean daily temperatures. Dr. McGonigle has found this to be true in the case of epidemics among hatchery fish.

Table 9. Mean Temperatures and Daily Food Consumption in Experiments A 1-2, B 1-2.

Experimental conditions	Fish No.	Mean Temp. Temp. °C	Mean Daily Food. Half-slices herring
Low Temp.; ration-fed	A 1	8.8	2.0
Low Temp.; well-fed	A 2	8.8	11.5
High Temp.; ration-fed	B 1	12.1	2.0
High Temp.; well-fed	B 2	12.0	17.6

The percentage monthly weight incremehts as well as the total weight and length increments (%) are given in table 10. In the two well-fed fish (A 2 B 2) the greatest increase in weight was in August and is due to the higher tmmperature in this month. But in the ration-fed fish (A 1 B 1) the best growth was in July and not in August when the temperature was greatest. The higher temperature increased basal metabolism and being on a ration diet the increase in growth would naturally be less. Considering next the growth during the full period of the experiment both lengths and weights gave essentially the same results. The well-fed fish (A 2 B 2) grew considerably better than the ratioh-fed fish (A 1 B 1). Of the well-fed fish B 2 at the high temperature showed better growth than A 2 at the low temperature. In the ration-fed fish just the reverse is found for A 1 at the low temperature showed better growth than B 1 at the high temperature. As just explained this is the result of the increased basal metabolism at the higher temperature.

Table 10. <u>Monthly Weight Increments and Total Weight and Length Increments (%) in Experiments A 1-2 B 1-2.</u>

		Low Temp.		High Temp.	
	Period	Ration-fed A 1	Well-fed A 2	Ration-fed B 1	Well-fed B 2
Monthly Weight Increments %	June 7-30	19.4	15.4	7.4	15.3
	July 1-31	35.1	41.7	26.4	67.2
	Aug. 1-31	22.0	61.8	13.6	81.3
	Sept. 1-24	17.2	27.3	13.6	13.7
Weight Increment %	June 7-Sept. 24	130.6	237.5	75.3	300.9
Length Increment %	June 8 - Sept. 24	28.2	41.8	19.0	45.9

Fig. 30. Daily temperature and food-consumption in experiments A 2 and B 2.

(c) Experiments A 3-4 B 3-4

This set of experiments is the same as the previous set expept it lasted for a longer time, namely one year in place of three and half-months. The four fish came originally from the St. John Hatchery as fry on July 11, 1933. The experiments were started on September 25, 1934 and completed September 24, 1935. The fish were 1^+ year-old parr at the beginning and 2^+ year-old at the end of the experiment. Two of the fish, A 3 and A 4, were kept at a low temperature, A 3 being ration-fed and A 4 well-fed. The other two fish, B 3 and B 4, were kept at a high temperature, B 3 being ration-fed and B 4 well-fed.

The mean temperatures and daily food-consumption will be found in table 11. During the fall and winter months the high temperature fish (B 3-4) were only at a slightly higher temperature than the low temperature fish (A 3-4). But during the four summer months there was a greater difference, the low temperature being 9.0°C and the high temperature 12.2°. For the first two months or more the food consisted of shrimp; during the winter and part of the summer up to July 15 the food was liver alone or liver plus dry feed; after July 15 the food was half-slices of herring. It was only during the latter period that an actual estimation of the feeding could be taken. During this period B 4 at the high temperature consumed almost twice as much food as A 4 at the low temperature The other two fish were fed only 2 half-slices of herring per day. During the winter months feeding was curtailed considerably by all the fish but it was more noticeable in the well-fed fish. Previous to the month of June the well-fed fish were only occasionally observed feeding whereas the ration-fed fish usually ate a little at each feeding. The difference, however, must have been merely in the time of feeding for the well-fed fish showed a greater increase in weight at this time than the ration-fed fish (see table 12, Nov. 26/34-May 4/35).

The daily temperatures and food-consumption in A 4 and B 4 experiments during the summer months are plotted in fig. 31. In B 4 the temperature rose steadily to a maximum of 17.6° on August 19, and thereafter declined. The amount of food consumed daily followed the temperature fairly closely except that the maximum was reached about a week previous to the maximum temperature. The maximum feeding was 60 half-slices of herring on August 13 when the temperature was about 15.8°. This is about the same maximum feeding temperature as found in B 2 experiment above. In A 4 the temperature increased from around 8° in June to 10.6° in August 19 and thereafter dropped only about a degree. The feeding increased rapidly at first and in August and September fluctuated around 18 half-slices of herring per day but can hardly be said to have reached any definite peak.

Table 11. Mean Temperatures and Daily Food Consumption in Experiment A 3-4 B 3-4.

Experimental conditions	Fish No.	Mean Temperature °C			Daily Food Half-slices herring July 15-Sept. 24/35
		Fall	Winter	Summer	
Low Temp.; ration-fed	A 3	8.2	5.5	9.1	2.0
Low Temp.; Well-fed	A 4	8.3	5.8	9.0	14.6
High Temp.; ration-fed	B 3	8.4	6.2	12.2	2.0
High Temp.; well-fed	B 4	8.6	6.3	12.2	24.9

The percentage increases in weight and length are listed in table 12. All the fish increased in weight during the fall and winter months but of course the greatest increases were in the summer months when the temperature was higher. The well-fed fish

(A 4, B 4) showed considerably better growth in practically every period than the ration-fed fish (A 3 B 3). However, during the winter period, November 26 - May 4, when the temperature was lowest the difference was not great. In the two well-fed fish (A 4 B 4) the increase was considerably greater in August, when the temperature was highest, than in any of the other months. In the ration-fed fish (A 3) at the low temperature the increases in July, August and September were practically the same since the temperature did not vary greatly in these three months. In the ration-fed fish (B 3) at the high temperature, however, the increase in August was considerably less than in July or September for in August the temperature was much higher than in the other two months. Thus the effect of temperature on basal metabolism and consequently growth can readily be seen in fish on a limited diet.

For the full-period of the experiment (1 year) the percentage increases in both lengths and weights show the following results. The two well-fed fish (A 4 B 4) showed much better growth than the ration-fed fish (A 3 B 3). The effect of temperature is not so great. Comparing the well-fed fish B 4 at the high temperature showed better growth than A 4 at the low temperature. But just the opposite effect of temperature is found in the ration-fed fish for A 3 at the low temperature showed somewhat better growth than B 3 at the high temperature. These results agree exactly with the similar experiments, A 1-2, B 1-2, on the effect of food and temperature on growth.

Table 12. Percentage Weight and Length Increments in Experiments A 3-4, B 3-4.

	Period	Low Temperature		High Temperature	
		Ration-fed A 3	Well-fed A 4	Ration-fed B 3	Well-fed B 4
Periodic Weight Increments %	Sept. 26-Oct. 26	-1.5	9.7	2.9	24.6
	Oct. 26-Nov. 26	1.5	7.4	2.8	14.0
	Nov. 26/34 - May 4/35	37.9	53.4	40.5	45.9
	May 4 - 31	3.3	16.1	4.8	14.0
	June 1 - 30	3.2	20.0	-2.8	25.8
	July 1 - 31	16.5	28.8	19.8	57.1
	Aug. 1 - 31	17.7	63.2	3.9	79.8
	Sept. 1 - 24	15.0	36.3	12.1	10.0
Weight Increments %	Sept. 26/34 - Sept. 24/35	131.8	621.0	111.4	823.2
Length Increments %	Sept. 25/34 - Sept. 24/35	44.4	99.3	37.8	108.1

Fig. 31. Daily temperature and food-consumption in Experiments A 4, B 4.

(d) Experiments F 5-6 F 1-2 in Saltwater

On May 20, 1936, a number of small parr and large smolts of the same age, namely 2+years, were brought from the St. John Hatchery to St. Andrews. They were kept in fresh water and in a short time practically all of the large smolts became fungoused whereas only a few of the small parr were so affected. On June 5 the large smolts affected with fungus were transferred to a large saltwater tank in the laboratory basement to rid them of the fungus growth. The salt water in this tank is pumped from the estuary of the St. Croix River and was a much easier method than dipping the fish in salt baths (3%). In a short time the fungus on all the fish was killed and on June 19 four of these smolts of approximately equal size were selected for the experiments which lasted until September 30.

Two of the fish, namely F 5 and F 6, were kept at a low temperature; F 5 was fed only 4 slices of herring a day and F 6 was fed all it wished to eat. The other two fish, F 1 and F 2, were kept at a high temperature; F 1 was fed only 4 slices of herring per day while F 2 was well-fed. The source of the water was the same for the four fish but the temperature of the supply to F 1 and F 2 was raised by means of an oil jacket-heater. The temperature of the supply to F 5 and F 6 was that of the river water which was lowered slightly by passing through a brine-cooler. The mean temperatures as well as growth, food-consumption and duration of experiments are listed in table 13. The mean low temperatures for F 5 and F 6 were respectively 11.7° and 11.8°C. The mean high temperatures were about 3.5 degrees higher, namely

F 1 15.3° and F 2 15.0°C.

The value of these experiments is limited by the fact that F 2 died after 81 days and F 6 after 103 days so the other two experiments were discontinued at this time. A considerable number of experiments were attempted in salt water but it was always found extremely more difficult to keep fish alive in salt water than in fresh water. In fresh water fish can be handled quite freely but in salt water they must be handled very carefully. In the first experiments attempted in salt water, the fish were wrapped in cheesecloth in order to hold them when scales were being removed. But in every case except one, namely S 3 experiment the fish died several weeks later before the experiment was completed. In fresh water this same procedure never resulted in even one death. In salt water the only time that any success was attained was when the fish were anaesthetized before handling. In this way the fish could be handled very gently and during the course of the experiment they were not even weighed for fear of injury. Even with such care two of the fish died. One of these fish, F 2, had the tip of the snout and lower jaw worn a little bit while F 6 had the tip of the lower jaw worn and the two mandibles disjointed at the anterior tip. Larger troughs would no doubt have been a decided advantage.

The two ration-fed fish, F 1 and F 5, quite ravenously ate the four slices of herring offered them each day. Of the well-fed fish, F 2 at the high temperature was feeding much better than F 6 at the low temperature for the first 46 days but after that time the feeding dropped off quite rapidly and several days before it died it refused to eat a thing. # 6 was feeding quite well for the first 75 days but after that the feeding steadily declined. The average food consumed per day by F 2 was slightly greater than F 6 but of course does not properly show the effect of temperature on feeding.

Concerning growth F 2 and F 6 show little of interest because of death. However, the two ration-fed fish (F 5 and F 1) were in good condition. F 5 at the low temperature showed better growth in both length and weight than F 1 at the high temperature; and in this respect they show the same effect of temperature and a limited diet as found in the two previous sets of experiments.

Table 13. Growth, Temperature, Food-consumption and Duration of Experiments F 5-6 F 1-2.

Experimental conditions	Fish No.	Length, of Expt. Days	Mean Temp. °C	Mean Daily Food Slices Herring	Length Increment %	Weight Increment %
Low Temp.; ration-fed	F 5	103	11.7	4.0	31.2	130.9
Low Temp.; Well-fed	F 6	103 (died)	11.8	8.4	37.2	182.1
High Templ; ration-fed	F 1	103	15.3	4.0	26.3	107.2
High Temp.; well-fed	F 2	81 (died)	15.0	8.4	25.6	84.1

ADDITIONAL EXPERIMENTS

(a) Starvation Scale-check Experiment (V_2).

The purpose of this experiment was to find out the effect of starvation on the formation of the ridges on the scale. It was carried out in fresh water on a salmon parr, 2+years old. This fish was retained with the reserve supply of fish at St. Andrews until the commencement of the experiment on July 28, 1935. It had been well-fed previous to the experiment and on July 28 it was moved into a separate trough, measured, weighed and a sample of scales taken. For 35 days, from July 28 to August 31, it was not given any food. From then on for the following 61 days until the end of the experiment on October 31 it was fed all it could eat.

Temperature, Food and Growth

The food consisted of whole slices of herring of approximately the same size, the fish being fed in the morning and in the afternoon the remaining slices removed. The daily food consumption and the daily temperature are plotted in fig. 32. The monthly temperature, food, and growth records are given in table 14. The temperature rose from around 11°C at the first of August to slightly over 14° in the middle of August. From then on it dropped steadily and was around 8° at the end of October. The mean daily temperature for August (during the starvation period) was the highest at 11.9°. It dropped in September to 10.5° and in October to 8.8°. The food curve is very interesting as it shows clearly the effect of starvation on subsequent feeding and also the effect of a decreasing temperature. For the first two days after the fast the fish ate 11.5 slices of herring per day which seems to be very little for a starving fish. During the next two or three days it ate still less and the amount fluctuated around 8 slices per day for the first half of September. After the middle of September it began to eat more and more each day until it finally reached its peak (25 slices) in the middle of October. And this in spite of the fact that the temperature was decreasing. But after the middle of October the low temperature began to show its effect for there is a general downward trend of the food curve to the end of the month. The daily food consumption for September was 10.5 slices of herring and slightly more (14.5) for October even though the temperature was lower. Consequently considerable variations in feeding reactions might readily be expected under the same temperature conditions at different times due to the physical condition of the fish. That the daily fluctuations in temperature and food do not coincide is quite evident from this experiment as well as others. The low food consumption during the two weeks of recovery succeeding starvation might be due to some extent to the shrinking of the stomach during starvation and the slow distention during recovery to accomodate the food. On the other hand, it might possibly be due entirely to some necessary physiological readjustment when feeding is resumed.

Table 14. Temperature, Food and Growth in Experiment V_2

Period	August	September	October	Whole Period
Mean Daily Temperature °C.	11.9	10.5	8.8	10.3
" " Food.	Starved	10.5	14.5	12.7
Weight Increments %	-9.8	68.4	27.7	94.0
Length Increments %	------	--------	-------	19.3

The length of the fish was measured at the beginning of the experiment on July 28 when the length to the mid-fork of the tail was 254 mm. For fear of injury to the fish it was not measured again until completion of the experiment on October 31, when the length was 303 mm. It thus increased in length 19.3% (49 mm) during the full time of the experiment. The weights were easier to take without danger of injuring the fish as the fish was weighed in water. It was weighed at the beginning of the experiment and at the end of each month during the experiment. At the beginning of the experiment it weighed 158 grams and at the end of August it weighed only 142.5 grams thus losing 15.5 grams of 9.8 per cent during the starvation period (35 days). In September it increased in weight 68.4 per cent and in October only 27.7 per cent. At the end of the experiment it weighed 306.5 grams thus showing an increase of 94. per cent (148.5 grams) during the full time of the experiment.

Scale Results.

On July 28 previous to starvation a sample of scales was removed from the left side of the fish near the dorsal fin and on October 31 when the fish was killed a similar sample of scales was removed from the right side. One of the scales taken at the end of the experiment is shown in fig. 33. The scales r moved at the beginning of the experiment had 9 ridges of summer growth since the last winter check. By counting out 9 ridges from the last winter check on the scal s removed at the end of the experiment the position on the scale, where the effect of starvation should be shown, was located. As can readily be seen from the photograph there is a very definite check in the growth of the scale at this point. The check is composed of about 6 ridges which are fairly close together and are incomplete at the sides of the scale, only 2 or 3 of them extending to the posterior part of the scale, but these are very close together. From this "starvation" check to the anterior edge of the scale there are 7 or 8 wide, regular ridges. The first 2 or 3 ridges of the check are irregular, incomplete and quite close together and were possibly laid down during the starvation period. The remaining ridges of the check are not so close together and are more regular. These we believe were laid down during the recovery period of about two weeks subsequent to starvation when the fish was not feeding so well. The wide ridges, from the check to the edge of the scale, were laid down when the feeding was greatest, namely from the middle of September to the end of the experiment. The reason for believing that the entire "starvation" check was not laid down during the starvation period is because other fish (see B_7) have been starved until they died (8 months) and there was no definite check on the scale. On the other hand there is reason to believe that the scale keeps on growing to some extent even after the fish has stopped growing. The description of this starvation check, i.e. narrow ridges being incomplete at the sides of the scale, fits the description of a winter check very well. The main distinction here, however, is the suddenness of the change from wide ridges to narrow ridges whereas in a winter check the change is usually more gradual.

Fig. 32 Daily temperature and food-consumption in experiment V_2.

Fig. 33. Experiment V 2; scale showing effect of starvation, followed by unlimited feeding, on growth; SC = starvation check. X 18.

(b) Starvation Experiments. (1 A 7, 2 A 7, 1B 7).

Scale absorption normally occurs in spawning fish and occasionally occurs at the sea winter check which had been noticed especially in fish from the St. John River. Since spawning fish cease feeding several months before spawning time, it was considered quite possible that the scale absorption might be due to starvation. Accordingly three salmon parr from the St. John Hatchery were scaled, measured, and weighed on October 2, 1934. Two of these, namely 1A 7 and 2 A 7, were starved until death while the third, 1 B 7, was starved until 17 days before death. The two fish, 1 A 7 and 2 A 7, were kept in the same trough with a screen partition between them. The fish, 1 B 7, was kept in a separate trough similarly divided by a screen partition.

Fish 1 A 7 was starved for 243 days, dying on June 3, 1935; fish 2 A 7 was starved for 247 days, dying on June 7, 1935. Fish 1 B 7 was starved from October 3, 1934, to May 31, 1935, i.e. for 240 days. From then on it was fed on ground liver but finally died on June 17, the length of the experiment being 257 days. The feeding prolonged the life of this fish by curtailing the loss in weight. From May 4 to May 31 when the fish was not being fed the loss of weight per day was 0.6 per cent. But from June 1 to June 17 when it was being fed the loss in weight per day was only 0.2 per cent. However, it really ate very little. The exact amount was not measured but is was only observed to feed on four different occasions. It acted similarly to other fish that had been starved in that it was not so much inclined to feed as one would expect.

The cause of death was similar in all three cases. The temperature of the water was between 5 and 6 degrees centigrade most of the winter. On May 18, 1935, they were shifted to another position in the experimental set-up where the temperature was higher. On May 22, 1 A 7 had fungus growth on its head, dorsal and pelvic fins. On May 23, 2 A 7 had some fungus on its head. On June 1, 1 B 7 had some fungus on its left pectoral fin. And once started this fungus growth increased from day to day. The fish were given 3 per cent salt baths to kill the fungus but the relief was only temporary. Their resistance was so low due to their starved condition that they were unable to combat the disease. The coefficient of condition for all three of the fish was very high at the beginning of the experiment but very low at the time of death. The respective coefficients of condition for 1 A 7, 2 A 7 and 1 B 7 before the starvation period were 1.13, .99 and 1.00; and at the time of death they were .64, .58 and .58 respectively. In computing the coefficient of condition the formula used was $K = \frac{100 \times W}{L^3}$ where W = the weight in grams and L = the length in centimetres from the tip of the snout to the tip of the middle ray of the caudal fin. This is the formula recommended at a meeting of the salmon and trout experts of Europe in 1933 (Menzies etc. 1934).

Lengths and Weights.

Lengths were measured, to the nearest millimetre, at the beginning of the experiment and at the time of death. On both occasions 2 A 7 and 1 B 7 had exactly the same length, namely 143 mm. and 148 mm. respectively. But 1 A 7 showed an increase in length of 2 mm.; its length on October 2, 1934, was 156 mm. and on June 3, 1935, was 158 mm. Whether this represents an actual increase in length or not is hard to say because an error of 1 or 2 mm. in measuring a live fish is more or less to be expected. On the other hand the fact that this fish was in very good condition (K = 1.13) at the beginning of the experiment favours the view that it really did increase in length even though being starved.

The three fish were weighed at the beginning and end of the experiments, and on three other occasions during the course of the experiments. The percentage loss of weight in days is given in table 15. Unfortunately the weighings were not taken at equal intervals of time so the loss of weight in different periods cannot be compared. The three fish, however, were weighed on the same dates and the loss in weight is remarkably uniform. For instance in 33 days the loss in weight varied from 5.2 to 7.7 per cent, in 213 days from 29.2 to 31.0 per cent, nd in 240 days from 37.9 to 40;0 per cent. The percentage loss in weight at the time of death shows even less variation. Fish 1 A 7 died on June 3, after 243 days of starvation, with a loss in weight of 40.7 per cent; 2 A 7 died on June 7, after 247 days of starvation, with a loss in weight of 41.4 pee cent; and 1 B 7 died on June 17, after 257 days of starvation, with a loss in weight of 41.5 per cent. The greatest variation in the loss of weight at the time of death in these three cases is 0.8 per cent. Therefore it appears that there is a fairly definite limit (about 41 per cent) in the loss of weight that a fish can endure.

The loss in weight was considerably greater in the month previous to death than it was during the first month of starvation. During the first 33 days of starvation from October 3 to November 5, 1934, the losses in weight were as follows:- 1 A 7 - 5.8 per cent; 2 A 7 - 5.2 per cent; and 1 B 7 - 7.7 per cent. During the 27 days from May 4 to May 31, 1935, the losses in weight were:- 1 A 7 - 11.7 per cent; 2 A 7 - 10. per cent; and 1 B 7 - 15.2 per cent. On May 18 it will be remembered the fish were transferred to a higher temperature and shortly after this the fish were attached with fungus. So these two factors of temperature and fungus growth are responsible for the greater loss in weight during the last month of the starvation period. It will also be noticed in these two periods that the percentage losses in weight were practically the same for 1 A 7 and 2 A 7 but was considerably greater for 1 B 7. Now 1 A 7 and 2 A 7 were subjected to the same temperature since they were in the same trough but 1 B 7 was in a separate trough and the temperature was slightly higher. The mean daily temperatures in these two troughs were: from October 3 to November 16, A 7 - 8.1 and B 7 - 8.3 degrees centigrade; from January 14 to May 1, A 7 - 5.8 and B 7 - 6.1 degrees centigrade; the mean temperature for A 7 - 7.2 and for B 7 - 7.4 degrees centigrade.

Some ideas of the peculiar appearance of these fish due to starvation might be gained from fig. 34. Practically all the loss in weight was from the body region of the fish, the head region suffering little, if any, from starvation. The body appears to be laterally compressed making the pectoral fins and head appear very prominent.

Fig. 34. Showing shape of fish 1 A 7, 2 A 7, and 1 B 7 (left to right) after a starvation period of approximately 8 months.

Table 15. <u>Percentage loss of Weight in Starving Fish.</u>

Date	Days	1 A 7	2 A 7	1 B 7
Nov.5/34.	33	5.8	5.2	7.7
May 4/35.	213	30.2	31.0	29.2
May 31/35	240	38.4	37.9	40.0
June 3/35.	243	40.7 dead		
June 7/35	247		41.4 dead	
June 17/35	257			41.5 dead

Scale Results

Scales were removed from the left side of the fish at the beginning of the experiment and from the right side of the fish at the end of the starvation period. These scales were compared for scale absorption, checks at the edge of the scale, number of ridges and lengths. None of the fish, either 1 A 7, 2 A 7, or 1 B 7, showed any definite check at the edge of the scale. However, some of the scales from each of these fish had 1 or 2 ridges at the edge of the scale which were slightly narrower than the preceding ridges but could hardly be called a check.

There was no sign of scale absorption which could be considered due to starvation, but there were a few cases of scale absorption mainly in regenerated scales which should be explained. In 2 A 7 neither normal nor regenerated scales showed any signs of scale absorption. In 1 A 7 there were no normal scales with any absorption but there were two regenerated scales with absorption. In this discussion only the scales which were regenerated in the summer (1934) previous to the experiment are being considered, all other scales are called normal. Of the above two scales one had a gouge at the side and the other at the anterior tip of the scale. So this scale absorption was local, affected both layers of the scale but mainly the upper layer, and was in two ridges from the edge of the scale. If, as we believe, this scale absorption occurred at the beginning of the experiment, it shows that there were two ridges laid down on the scale during the starvation period. Also the 1 or 2 ridges at the edge of normal scales from this fish, 1 A 7, appeared narrower than in the scales from the other two fish. And it will be remembered that 1 A 7 was in better condition than the other fish at the beginning of the experiment and also increased in length 2 mm. during the starvation period. So apparently there was some scale growth during the time of starvation.

In 1 B 7 one or two normal scales and quite a number of regenerated scales showed local gouging due to scale absorption. There was no regularily to this scale absorption. It occurred at the sides and tips of the scale, and included both layers of the scale but especially the upper layer. The gouges are quite deep and they differ from those in 1 A 7 in that they are not filled in with subsequent growth. Now the examples of scale absorption outlined are the exception rather than the rule; there was no regularity to the absorption; and it occurred almost exclusively in regenerated scales. For that reason it was stated that there was no scale absorption due to starvation. The cause of the scale absorption in a few of the scales was the loosening or displacement of these scales during the handling of the fish at the beginning of the experiment. It has been demonstrated that scale absorption may be produced in that manner (see V 9). Just why it occurred mainly in regenerated scales is perhaps because these scales would not be so firmly set in the scale pockets.

Creaser (1926) claims to have experimentally produced marginal absorption of the scale in a bluegill (Helioperca incisor) and a small-mouther bass (Micropterus dolomieu).

He found that not all the scales were involved but especially those of the side. So it is more than likely that the absorption he observed was due to displacement of the scale rather than starvation.

The lengths of the scales were measured from the focus to the anterior tip of the scale. The ridges were counted from the last winter check to the anterior edge of the scale. The results of these measurementw before and after starvation are given in table 16. In each of the fish the average number of ridges after starvation was greater than before starvation. The difference was between one and two ridges. Also the average lengths of the scales in the three fish were greater after the starvation period than they were before starvation. The difference is quite considerable. Since the scales before starvation were taken from the left side and after starvation from a similar position on the right side, a correction is necessary. For it had been found that the lengths of scales on the right side are about 4.5 per cent greater than those from the left side. So the sca le lengths before starvation have been increased 4.5 per cent and still the scale lengths after starvation are greater by about .04 to .06 mm. This difference in the lengths of the scales would be equal to one to two ridges for a number of the ridges have been measured and the average width of the ridges is about .03 mm. Apparently then there is a perceptible growth of the scales when the fish is being starved even though there is no increase in the length of the fish.

Table 16. Scale Lengths (mml) and Number of Ridges (from last winter check) before and after Starvation.

Fish No.	1 A 7.		2 A 7.		1 B 7.	
Starvation	Before	After	Before	After	Before	After
No. of Ridges	17.9	19.2	16.5	18.4	16.2	18.3
Scale Lengths mm.	.988	1.070	.789	.888	.800	.873
Corrected Scale Lengths mm.	1.032	1.070	.825	.888	.836	.873

(C). Sexual Maturity and Concomitant Changes in Scales and Feeding (D 4).

In the spring of 1934 a grilse was captured in a salmon weir in St. John Harbour. It was transported to St. Andrews and retained in the brackish water of the St. Croix River near the Atlantic Biological Station during the summer of 1934. This was in connection with Dr. Huntsman's experiments on the effect of salinity on maturity. This experiment was completed on November 3, 1934 and the fish was transferred to a large tank in the basement of the Biological Station. It was retained here in brackish water, which is pumped from the river, until its death on July 20, 1936, i.e. for 625 days or almost two years. The original intention was to use this fish in a feeding experiment but this was found impossible due to the fact that it would not feed regularly.

The weight of the fish at the time of death, July 20, was 5 pounds; its length to the mid-fork of the tail was 62 cm.; it was a male grilse which was to be expected since most of the grilse are males. The cause of death might readily be assigned to confinement since the snout and tip of the lower jaw were worn considerably, also the bases of the pelvic fins as well as the tips of all the fins. These points mentioned would be the surfaces striking the bottom and sides of the tank. Of chief interest, however, is the fact that the fish refused to eat in the fall of the year during the time of sexual maturity.

Feeding and Temperature Records.

As mentioned previously, this was not a planned experiment and for that reason the records are not as complete as they might have been. The temperature records were taken from a thermograph operating in an adjoining tank but the source of the water supply was the same and the temperature in the two tanks should differ very little. The food consisted of whole herring, about sardine size, and occasionally clams.

The daily temperatures are shown in fig. 35 and the mean monthly temperatures are given in table 17. In 1935 the lowest temperature was in March with a mean of 3.1°C. Thereafter, the temperature increased regularly from month to month until a maximum of 13.6°C. was reached in August. It remained high (13.0°C) in September but dropped fairly rapidly during the fall and winter to a minimum of 0.6°C in February, 1936. In March and succeeding months the water warmed up again and the temperature was still rising in July when the fish died.

Table 17. Mean Monthly Temperatures (D 4).

Year	Month	Degrees Cent.
1935	Feb.	4.8
	March	3.1
	April	4.9
	May	5.8
	June	9.3
	July	12.4
	Aug.	13.6
	Sept.	13.0
	Oct.	9.8
	Nov.	7.6
	Dec.	3.5
1936	Jan.	1.7
	Feb.	0.6
	March	3.0
	April	4.7
	May	7.5
	June	10.4
	July	11.1

A complete feeding record of this fish was kept and the number of herring eaten daily is shown in fig. 35. A number of times clams were thrown in to the fish, but altogether it ate only four so in the chart these have been included with the herring. During the fall and winter of 1934-35 it would not eat at all, but this was not considered exceptional because of the handling and the new environment it was confronted with which usually upsets a fish. In April of 1935 the mean temperature rose to 4.9° and in the latter part of

April the fish started to feed. In May, June, and July as the temperature rose the feeding increased. The maximum feeding was in July, but at the end of the month and during August the feeding started to drop off. It dropped off so rapidly that it was eating only one herring a day during the last two or three days of August. During the first week of September it ate only two herring and after that refused to eat. So it is quite apparent that the feeding does not coincide exactly with the temperature, for the maximum temperature occurred in August in which month the feeding was dropping off; and again in September the temperature was still high and the fish ceased feeding after the first week of this month. Some factor other than temperature must have influenced the fish to cause it to cease feeding at this time. If it were temperature, one would expect a more gradual sloping-off of the feeding curve to correspond with the down-trend of the temperature curve. From October to February the temperature decreased gradually and during the whole of this time the fish refused to eat a thing. The temperature started to increase again about the middle of February and rose steadily from then on. The fish fed occasionally during March and April, and about the middle of May started feeding quite regularly again. Thus the commencement of feeding after the winter fast seems to be quite definitely related to the warming up of the water both in the spring of 1935 and 1936. After June 4th the food record is incomplete for the fish was fed slices of herring and the actual amount eaten was not recorded. However, it did feed regularly up until the end of June, but during July previous to its death on July 20 it ate very little.

Feeding Reactions.

When feeding the fish, the herring were usually thrown into the tank faster than the fish could eat them. In this way there would be herring on the bottom of the tank as well as some dropping in the water. The herring moving in the water were always eaten before those lying on the bottom. When all the moving herring were cleaned up, it would then start eating off the bottom if it was hungry enough. It seemed to have difficulty in perceiving the herring on the bottom and also had more difficulty in picking up the food off the bottom.

During the fall and winter when it refused to eat, usually it would pay no attention to the food thrown into the tank. But on several occasions, eight to be exact, it was observed to dart after a herring or clam, take it into its mouth and expell it again. Usually it made no attempt to swallow the food, but on February 3, 1936, it took a herring in its mouth and appeared to be trying to swallow it as it opened wide its mouth and gill covers several times, but finally spit out the herring. One might have thought that, due to the low temperature, the muscles of the oesophagus had contracted so that it could not swallow, had it not gone through the same manoeuvres on March 20 with several clams just six days after it had eaten four herring. Apparently, then, the fish had no desire to eat and the act of taking the food and even going through the swallowing motions are merely instinctive or reflex actions.

<u>Scale Readings and Spawning Marks.</u>

The scales (fig. 36) show 2 years of river growth, 1+ years of sea growth and 2 spawning marks making the age of the fish 5 years at the time of its death in 1936. When the fish was transferred to the salt water tank in 1934 it was 3+ years old, the scales showing 7 ridges of sea growth for that summer; it spawned in the winter of 1934-35; during the summer of 1935 it produced 11 scale ridges and spawned again in the winter of 1935-36; during the summer of 1936, previous to July 20, it produced 5 scale ridges. The 7 ridges of growth produced during the summer of 1934 under natural conditions in the sea are wider apart than those produced in the tank during the summers of 1935 and 1936. We may conclude, then, that better growth is produced under natural conditions than during confinement.

The pertinent fact revealed by the scales is that the fish was sexually mature in the fall of 1934 and again in the fall of 1935. As these periods coincide with the periods when the fish refused to eat, it would seem that sexual maturity might be the cause of the cessation of feeding rather than temperature since, as noted above, the food curve dropped much sooner than the temperature curve.

Fig. 35. Daily temperature and food-consumption in experiment D4.

Fig. 36. Experiment D4; scale showing two spawning marks produced while fish was retained in saltwater; age 2.1 + SM + SM + (2 years fresh water, 3+ years saltwater); SM = spawning mark. X 11.

In the case of the grilse (D 4) retained in a saltwater tank the changes associated with sexual maturity were scale absorption and cessation of feeding. The identical conditions occurred on two occasions, in the fall of 1934 and in the fall of 1935. Are these changes produced only under artificial conditions or are they comparable with what occurs under natural conditions?

The mature salmon along the coast collect in the surface layers of water near the mouths of rivers in early spring and summer. Runs of salmon enter the river in the spring, at odd favourable occasions during the summer and in the fall. Dr. Belding has kindly supplied some information on the feeding of Miramichi fish in 1930. From the drift-net fishery at the mouth of the river 485 salmon were examined and only 7.2 percent had food in the stomach. The weekly percentages of drift fish with food were as follows:

Week ending	June 21	---	18.6 per cent
" "	" 28	---	8.1 " "
" "	July 5	---	7.5 " "
" "	" 12	---	3.3 " "
" "	" 19	---	4.2 " "

After July 19 no salmon with food were taken. Of 249 salmon examined from the river fishery near Millerton, about 36 miles from the mouth of the river, only 1 fish or 0.4 per cent had food in the stomach. In the drift fishery of the St. John River from June 22 to July 27, 1932, we examined 107 fish and 15.9 per cent had food in the stomach. Therefore under natural conditions the salmon cease feeding even before entering the river. A greater percentage are feeding early in the summer than later on, when the sexual organs would be more fully developed. So the same relation between feeding and sexual maturity is found under natural conditions as was found under artificial conditions.

Accompanying the ripening of the gonads the periphery of the scale is gradually absorbed, beginning at the posterior edge of the scale and working forward. In 1931 an excellent opportunity was afforded of studying the scales of Miramichi fish composing the river and drift fishery from the beginning of June until the middle of October. The percentage of these fish showing scale absorption in half-monthly periods is given in table 18. The percentage for the total of drift and river fish shows that there are no fish showing scale absorption during the first half of June. During the latter half of June there are only 0.6 per cent but in July the percentage increases rapidly from 19. per cent during the first half of July to 87.5 per cent in the latter half. For the remainder of the season the percentage increases more slowly and reached 100 per cent in October, i.e. all the fish in October had scale absorption. Of the total sample of 1557 fish for the year, 58.2 per cent showed scales with absorption. Fish with scale absorption appeared in the latter half of June in the river fishery (1.5%) and not until the first half of July in the drift fishery (23%). In both drift and river fish the percentage increased fairly regularly as spawning time approached but one peculiar thing is that the percentage for July is considerably higher in the drift fish than in the river fish.

Table 18. Percentage of river and drift fish of Miramichi River, 1931, showing scale absorption in half-monthly periods.

Date	River	Drift	River and Drift	Number of fish
June 1-15	0.0	0.0	0.0	137
16-30	1.5	0.0	0.6	310
July 1-15	7.5	23.0	19.0	205
16-31	79.2	96.1	87.5	257
Aug. 1-15	99.6	--	99.6	224
16-31	97.2	--	97.2	143
Sept. 1-15	99.0	96.9	98.4	129
16-30	98.9	100.0	99.1	116
Oct. 1-15	100.0	--	100.0	36
Total	72.6	35.3	58.2	1557

Although scale absorption first appears along the periphery of the ridgeless posterior part of the scale, this part of the scale was neglected in recording the extent of absorption for the simple reason that it is hard to detect here due to the absence of ridges. In recording the extent of scale absorption the periphery of the ridged area was considered as divided into three equal dimensions, division 1 being the posterior third of the ridged area, division 2 the middle third, and division 3 the anterior third, right to the anterior tip of the scale. The average extent of scale absorption was recorded in all of the sea groups of Miramichi fish in 1931 from the beginning of June until the middle of October, but only the 2+ sea group (2+ winters in the sea) is given in table 19 as it is the most representative group. During the first half of June there were no fish with scale absorption; and during the second half of June scale absorption was 2.0 (only 2 fish) for the river fish and there were no drift fish with absorption. In the first half of July the scale absorption was 1.3 for the river fish and 1.2 for the drift fish; in the second half of July it was 2.3 for both river and drift fish. There was no drift fishery in August but the river fish showed a scale absorption of 2.7 in the first half of August and extended to 2.9 in the second half of August. During the whole of September and October the scale absorption was 3.0 in both river and drift fish, i.e. it has extended to the anterior edge of the scale. All the other sea groups of fish also showed a similar increase in the average amount of scale absorption as the season progressed. Since the extent of the scale absorption increases as spawning time approaches, it must in some way be connected with the ripening of the gonads.

Table 19. Extent of Scale Absorption in river and drift fish of 2+ Sea Group in Miramichi River, 1931.

Date	River	Drift
June 1-15	0.0	0.0
16-30	2.0	0.0
July 1-15	1.3	1.2
16-31	2.3	2.3
Aug. 1-15	2.7	--
16-31	2.9	--
Sept.1-15	3.0	3.0
16-30	3.0	3.0
Oct. 1-16	3.0	

Numerous theories have been proposed to account for scale absorption. Johnston (1905) and Dahl (1911) believed it was due to the mechanical vicissitudes of river-life. Later Johnston (1906) suggested compression of the scales due to loss in weight as the explanation of absorption. Masterman (1913) believed that it could not have its origin in the manner assumed by the above authors because the conditions was produced prior to entering the river. He suggested that the process may be an anticipatory reductioh of the size of the scale to meet the approaching reduction in girth of the body, or it may be connected directly with the formation and development of the ova. Crichton (1935) found that at least some of the same cells which are responsible for the laying down of the scale are also the ones concerned with the absorption of the scale material. In connection with the relation of scale absorption to the ripening of the sexual organs, he does not believe that the scale-material is used directly in their elaboration. He suggests that the sdale material might make good a deficiency of a necessary substance, perhaps calcium, in which case it would be parallel with the condition in a pregnant mammal where calcium-deficiency is restored by the absorption of material from the teeth and bones. If this were the case, one would expect to find more extensive scale absorption in females than in males. But on the contrary absorption is far more extensive in male scales than in female scales. In fact sometimes practically the whole scale is abosrbed in males which never occurs in female scales. This fact was first noted by Menzies (1925) in Scottish salmon and is also quite evident in our scale collections from Canadian salmon.

Since 30 to 50 per cent of the Teleost scale is inorganic material, chiefly calcium phosphate, Someren (1937) recently had hopes of discovering the cause of scale absorption by calculating the serum calcium values of a series of migrating salmon in relation to the degree of scale absorption. He found that female salmon show a progressive rise in serum calcium level until just before spawning, when it drops to subnormal, and remains subnormal while the fish is a kelt.

In the male salmon, on the contrary, it remains fairly constant until just before spawning, when it drops to subnormal. This variation in serum calcium he found was independent of the weight, length, condition and degree of scale absorbtion. It is believed to be a secondary phenomenon incidental to pituitary activity and growth of the gonads as in amphibia and birds. The major cause of scale absorption he believed to be a potential mineral deficiency during the migration fast. He attempted to induce artificial absorption by feeding brown trout on a calcimm-deficient diet but was unsuccessful. We had the same idea that fasting might produce scale absorption and a number of salmon parr were starved for 8 months but absorption of the scales could not be detected. He decided that in male salmon the absorption is probably accentuated by a demand for calcium for the development of secondary sexual characters, thus accounting for the greater degree of absorption exhibited by males. This idea presupposes some utility in the secondary sexual characters which is very doubtful. (Tchernavin, 1938).

Although his results are interesting, we do believe there is another explanation of the facts concerned which, for the present at any rate, seems to be more satisfactory. Scale absorption quite commonly occurs in scales which have become twisted in the scale pocket; in these cases there is no connection with spawning whatsoever. In the new position of the scale the long axis is sideways of the scale pocket so that the anterior and posterior (or anterior-lateral and postero-lateral) edges of the scale are pressing against the sides of the scale pocket. It is at these points that scale absorbtion usually occurs. It is quite possible then, that the absorption of the scales in spawning fish is produced in a similar manner if the pockets shrink in size at this time. This, however, is not known, but may in some way be connected with the thickening of the skin at spawning time which is quite noticeable especially in male fish. If such a mechanical explanation of absopption is correct, it can readily be understood why the absorption commences at the posterior end of the scale and is greatest in this area. The reason for the scales of male fish showing greater absorption than the scales of female fish would also be clarified. In the next experiment (F 3) to be considered scale absorption was found under conditions which cannot be reconciled with these views.

(d). Scale Absorption and Splenectasis (F 3)

A 2+ year-old smolt from the St. John Hatchery was transferred directly from fresh water to salt water on June 25, 1935. The daily food and temperature are plotted in fig. 37. For the first 39 days of the experiment from June 25 to August 3 the fish was well-fed, the mean daily food consumed being 5.8 slices of herring. From August 4 to September 30 (97)days) it was fed only 2 slices of herring a day. From August 4 to August 25 (22 days) it ate the 2 slices of herring for several days but later ate only 1 slice and some days none at all. From August 26 to September 30 (36 days) it absolutely refused to eat even one slice. The plan of the experiment was to start feeding the fish all it wished to eat again after a short period of ration-feeding but, of course, this was impossible now that it would not even eat its ration-food. The two slices of herring, however, were thrown in to it every day and the peculiar thing was that, even though it would not eat even a part of a slice, it invariably took the slices in its mouth and tore them in bits. The mean temperature during the experiment was 15.5°C.

The length of the fish at the beginning of the experiment was 190 mm. and at the end of the experiment 208 mm., an increase of 9.5 per cent. The weight increased from 60.5 grams at the beginning to 70.0 grams at the end of the experiment, i.e. 15.7 per cent.

Scale Results.

Scales were removed at the beginning and end of the experiment. Scales removed at the beginning had a transference check about 2 or 3 ridges from the second winter check and in one or two ridges from the edge of the scale. This check was laid down when the fish was transferred from the St. John Hatchery to St. Andrews on May 20, 1936. Fig. 38 is a photograph of a scale removed at the end of the experiment. The various checks and the beginning of the experiment consists of about 3 fairly wide ridges, followed by 4 - 5 narrower ridges, and at the edge of the scale 2 - 3 very narrow ridges. The interpretation is as follows. The first

3 or so wide ridges were laid down during the first 18 days of the well-fed period when the feeding was between 3 and 6 slices of herring per day and the temperature rising from 11 to 15°C. The next 4 - 5 ridges, which were somewhat narrower, were laid down during the following 21 days of the well-fed period when the feeding was between 5 and 9 slices per day and the temperature between 15 and 17°C. The 2 - 3 narrow ridges at the edge of the scale were laid down during the ration-fed period.

Along both sides of the scale will be noticed a fair amount of absorption. Both layers of the scale wee absorbed but usually the outer layer is more absorbed than the inner. The figure represents about the average amount of absorption. Practically all the scales examined were absorbed at one place or another, but a few were not absorbed at all, or if they were it was not very noticeable. Some were absorbed only slightly while others were extremely absorbed. Scales were examined from four different places on the fish and they all showed the absorbed condition. The absorption, therefore, was certainly not caused by scale displacement or a local injury. It must be something affecting the entire fish. The fish was an immature female so it is in no way connected with sexual maturity. Since the absorption was at the edge of the scale and not filled in by subsequent growth it certainly occurred during the latter part of the experiment when the fish refused to eat. But it has been shown elsewhere that starvation alone will not produce scale absorption. When the fish was opened the spleen was found to be very black in colour and abnormally large which might in some way be connected with the scale absorption. The enlarged spleen was 3 or 4 times the size of a normal spleen and is shown in fig. 39 compared with a normal spleen in a fish of the same size, namely 208 mm. The abnormal spleen was sectioned and examined by Dr. Robinson of the Banting Institute. He found considerable fibrosis of the spleen and indications were that it was a disease similar to Banti's Disease but of this he could not be sure without more material. He did not believe, however, that it was the result of cessation of feeding.

Another example of splenectasis being associated with scale absorption was found while working over the salmon and trout material collected by Drs. Huntsman and Leim in Cape Breton Highlands National Park, August 1-3, 1937. The fish was a 2+ year-old parr, 131 mm. in length, and was taken in Roper Brook on the east side of the island. There was a check in the third summer's growth about 5 ridges from the edge of the scale. The check was present in all the scales but in some of the scales there was slight absorption and in others there was extreme absorption. Scales were removed from three different positions on the body and the same conditions were found in each case. It was then decided that the absorption was not due to scale displacement and upon opening the fish the spleen was found to be enlarged. But it was not so large as the one found in fish F 3 which merely means that the fish was in the recovery stage for the absorption and check were not at the edge of the scale but 5 ridges from the edge so the critical stage was passed a month or so previously.

There was another check during the same summer's growth about 9 ridges from the edge of the scale. There were only 2 scales showing extreme absorption at this check so it is difficult to say if it has any relation to splenectasis or not. But in fish F 3 there was slight scale absorption at the second winter check and at the transference check in addition to the extreme absorption at the edge of the scale (see fig. 38). In this case it does seem that the scales are susceptible to absorption whenever the fish is not feeding very well but, of course, it is impossible to say that the absorption was due to or associated with an enlarged spleen in each instance. In this connection the observations of Miescher-Ruesch (1880) on the spleen of mature salmon are interesting. He found that in May it is of normal size, solid and brown in colour. When the fish starts up the river it begins to increase in size. At the end of July it is 15 - 20 times heavier than normal and assumes a dark-red colour and soft consistency. It would be hard, however, to dissociate the effects of fasting and of sexual maturity in spawning fish.

Fig. 37. Daily temperature and food-consumption in experiment F 3

Fig. 38. Experiment F 3; scale from fish with abnormally large spleen showing absorption at periphery; A = absorption WC = 2nd winter check; TC = transference check; WF - well-fed; RF = ration-fed. X 21

Fig. 39. F 3 on the left and A 3 on the right, fish of same length, dissected to show abnormal size of spleen in F 3.

(c). <u>Scale Displacement Experiment. V 9.</u>

Quite commonly in wild fish scales may be found which have apparently been twisted in the scale pocket. These scales often show varying degrees of scale absorption. Again scales often show considerable absorption without being twisted in the scale pocket but were perhaps dislodged in an antero-posterior direction. It is immediately apparent that a slight dislodgement of a scale may produce a check on the scale with or without scale absorption depending on the amount of movement. To elucidate some of these observations and ideas an experiment in this direction was attempted on a salmon smolt.

On October 2, 1935, the fish was anaesthetized with ether. On the right side of the fish in line with the posterior base of the dorsal fin and immediately above the lateral line about 10 scales were removed from their pockets and put back in place again. In a similar position but in line with the anterior base of the dorsal fin the skin was rubbed sufficiently to loosen the scales without removing them entirely. A few were, however, accidentally removed in this operation.

From then on for 61 days the fish was not handled in any way. It was given all it wished to eat and the temperature was uncontrolled (fig. 40). Both the temperature and feeding varied considerably from day to day and both showed a general decline from the beginning of the experiment to the end. The temperature dropped from around 10°C to about 6°, the mean temperature being 7.9°C. The feeding dropped from around 12 to about 3 slices of herring per day, the mean value for the two months' period being 7.0 slices per day. Apparently the administration of ether and handling etc. did not upset the fish very much for the operation was performed at 3.45 p.m. and at 4.30 p.m. it ate 4 slices of herring. The growth during the experiment was 16 mm. or 6.1 per cent, the length on October 2 being 263 mm. and on December 2, 279 mm. The fish was weighed at the completion of the experiment only, the weight then being 242 grams.

Scale Results.

As the operations of removing and rubbing the scales were performed on the right side of the fish, it was necessary to remove scale samples from the left side of the fish to determine normal scale growth previous to and during the experiment. Examination showed that sometime previous to the experiment a very definite check was formed on the scales. From this check to the beginning of the experiment there were about 6 wide ridges indicating good growth previous to the experiment. During the experiment the ridges laid down were about 4 in number and were a little narrower indicating poorer growth. This was due to a decreasing temperature and consequently decreased feeding as shown in fig. 40.

The scales were then examined on the right side of the fish, first at the posterior area of the dorsal fin where the scales had been removed and inserted back in the scale pockets. The scales in these pockets, however, proved to be regenerated scales, the commencement of regeneration coinciding with the beginning of the experiment. This result was more or less anticipated because during the removal of the scales it was found very difficult to prevent the dislodgement of scales previously removed and inserted back in the pockets. Although we did manage to put the fish back in the water with these scales in the pockets, the flexion of the body would be sufficient to dislodge them again.

In the area at the anterior end of the dorsal fin, where the skin had been rubbed, the scales were also mounted separately and examined. These scales had a check about 4 or 5 ridges from the edge of the scale and there is no doubt but that it was produced by the displacement of the scales in their pockets. The most extreme case is shown in fig. 41. In this example the displacement of the scale in the pocket caused the scale to be absorbed all the way around the edge and the absorption included both layers of the scale. The most extreme absorption, however, was at the posterior edge of the scale. Surrounding the absorbed edge of the scale are 3 or more ridges of new growth. The resulting check is quite similar to a spawning mark except perhaps that the contour is more regular thus lacking the ridgeless scars so characteristic of spawning marks. In the left anterior edge will be noticed an indentation. In this location was situated a small piece of scale material which was attached to the scale only at the anterior tip of the scale. The anterior half of this piece of scale material contained ridges and filled in the indented area of the scale; the posterior half was ridgeless and projected beneath the scale. That the scale absorption is in some way connected with the separation of the scale from its surrounding pocket is quite clear, but the mechanism at work is not so evident. Neave (see Someren 1937) believed that certain cells were active in hollowing out the scale material to form ridges and that the absorption was due to the continued activity of these cells after the scleroblasts had ceased laying down scale material. This hypothesis, however, does not fit in with the facts for the posterior part of the scale contains no ridges and it is here that scale absorption is greatest in spawning fish.

There was considerable variation in the checks presumably depending on the amount of movement in the scale pockets. Some of the scales were absorbed at the posterior edge while others were absorbed only at the anterior edge. While others again showed only slight absorption of the outer layer only. Fig. 42 is an example of the latter. In such cases it is very difficult to say whether scale absorption is represented or not. For normal scales quite often have indistinct ridges in the process of formation at the edge of the scale and if these ridges were left incompleted it would give the appearance of slight scale absorption. In many of the scales at any rate the new ridges formed after the check were not parallel with the old ridges and the new growth appeared quite similar to that found after a spawning mark. The two most prominent features, then, of a "displacement" check (when the scales are not distorted much) are scale absorption and the irregularity of the direction of the ridges. Jarvi and Menzies (1936) evidently did not know that a displaced scale might be absorbed at the edge. In discussing pseudo spawning marks due to an injury to the skin and consequent displacement of the scales they noticed that the junction of the growth before and after the injury leaves a scar on the surface. Concerning the resemblance to a spawning mark they say: "Such scar, however, if carefully examined does not closely resemble that of a true spawning mark since the edge of the scale at the scar is intact and not serrated as is the case after absorption."

Fig. 40. Daily temperature and food-consumption in experiment V 9

Fig. 41. Experiment V 9; scale showing very definite check (DC) with much absorption due to displacement in pocket.

Fig. 42. Experiment V 9; scale showing slight check (DC) with little or no absorption due to displacement in pocket; on left side note that outer 4 ridges are not parallel with previous ridges

(f) Regeneration of Scales (N_1).

When a fish loses a scale, accidentally or otherwise, a new scale grows in its place which is abnormal in the sense that it has a large focal area without any ridges. Such abnormal scales are usually spoken of as regenerated scales and are frequently encountered in scale studies. An experiment was carried out primarily to determine the rate at which such scales are regenerated. Both Scott (1911) and Creaser (1926) have shown experimentally that lost scales will be replaced by scales with large focal areas.

The experiment was conducted in fresh water on a 2+year-old salmon smolt, which was obtained on May 20, 1936 at the St. John Hatchery. On July 17, 1936 it was anaesthetized in ether solution and the second to the sixth scales dorsad from the lateral line were removed from a row of scales on the right side of the body near the adipose fin (fig. 43). This row of empty scale pockets was used as a guide mark in the removal of other scales. From the third antero-posterior row of scales dorsal to the lateral line the fifth scale anterior to the guide mark was also removed on the same date. Later every other scale was removed from this row of scales at intervals of time decreasing from 9 days to 1 day. For example, the seventh scale was removed 9 days after the fifth, the ninth scale 8 days after the seventh and so on. (table 20). The fish was killed one week after the last scale had been removed. The exact position of guide mark scales and the antero-posterior row of scales may be seen in fig. 43.

Growth Rate of Regenerating Scales.

Before removing the regenerated scales from the scale pockets a diagram was made of the appearance of the exposed portion of these scales in relation to the normal scales surrounding them. (fig. 44). The guide mark scales and scale number 5, which have been regenerating for 59 days appear to be of normal size as well as scale number 7 which has been regenerating for 50 days. Scale number 9 regenerating for 42 days as well as all the other scales of less regeneration time are quite noticeably smaller than adjacent scales. Scale number 23 regenerating for 8 days was barely evident while scale number 25 regenerating for 7 days was not exposed at all and incidentally could not even be found in the scale pocket. Of course it is hard to say whether a very small scale was present or not but since there was no difficulty in finding scale number 23 it is quite possible that several days intervene before the formation of a new scale.

In determining the rate of scale growth the dimension most commonly used is the distance from the focus to the anterior edge of the scale. As young regenerating scales do not have any ridges in the centre of the scale to form a definite focus the two diameters were measured, the longitudinal or antero-posterior and the transverse or dorso-ventral. In fig. 45-46 the rate of growth of each regenerating scale is compared with the size of the scale that originally occupied the same pocket. The antero-posterior diameter of the regenerating scale increases very rapidly for the first 17 days and from the 17th to the 59th day the increase is more or less uniform but not nearly so great. After 50 days the regenerating scale is exactly the same size as the original scale and after 59 days the regenerating scale is larger than the original scale. Thus it is quite obvious that the fish has been growing during the experiment. The dorso-ventral diameter of the regenerating scale increases more rapidly than the antero-posterior diameter as it reaches the size of the original scale in about 35 days. So, if the fish had not grown any during the experiment the rate of scale regeneration would have been 50 days for the antero-posterior diameter and 35 days for the dorso-ventral diameter.

In order to determine the time it takes the regenerating scales to catch up to the normal rate of the fish it is necessary to compare the size of the regenerating scales with the size of scales which had not been removed during the experiment. Obviously normal scales from any part of the body will not do as these vary considerably in size. Two methods have been employed as outlined below.

In the row of scales on the right side of the fish containing the regenerating scales there is a normal scale on either side of each regenerating scale so the average value of the two scales adjacent to each regenerating scale should be a fairly representative value of normal growth with which to compare the size of the regenerating scale. These results are shown in fig. 47-48. Both the antero-posterior and the dorso-ventral diameters of the regenerating scales almost reach the normal scale size in 50 days but neither actually reaches the normal even after 59 days. The last part of the curve for normal scale size is somewhat lower than it should be because one of the scales used in averaging the last two points was a regenerating scale and consequently smaller than normal scales. As this is the important part of the curve it would be better to compare the size of the regenerating scales of the right side with the size of corresponding normal scales from the left side. Exactly corresponding scales were easily determined by following the guide mark row of scales of the right side dorsalward over the back of the fish to the left side and in the third row of scales dorsal to the lateral line on the left side the required scales were counted forward from the guide mark. In fig. 49-50 are the curves showing the relation between the size of these normal scales of the left side and the size of the regenerating scales. Here again the antero-posterior diameter of the regenerating scales has not reached normal scale size even after 59 days. The dorso-ventral diameter on the other hand reached normal size in 40 days.

So from the above results on the rate of growth of regenerating scales it may be said that the dorso-ventral diameter increases at a faster rate than the antero-posterior diameter and reaches the size of the original scale in about 35 days and the size of normal scales in about 40 days. The antero-posterior diameter does not reach the size of the original scale until about 50 days and did not reach the size of normal scales even after 59 days; as the experiment lasted only 59 days it cannot be said just how long it would take this diameter to attain normal growth.

On examining regenerating scales from this same fish other than the ones experimented on it was noticed in a large number of them that the exposed posterior field of the scale is much smaller and narrower in relation to the remainder of the scale than is the case in normal scales. Figure 53 is a striking example of this condition. As will be noticed also in this figure the posterior field of the scale is distorted from the main longitudinal axis of the scale. This distorted condition, however, does not occur as frequently as does the smallness of the posterior field. On fish F 5 a number of small regenerating scales were noted and in removing these scales it was very difficult to get the forceps in under the posterior end of the scales. Presumably the reason for this was that these scales had not yet grown up into the overlying epidermis. So what we believe happens, when a scale is lost, is that the broken ends of the epidermis grow together before the new scale fills the pocket. As the new scale increases in size it has to force its way into the epidermis. This view would explain the smallness of the posterior field of a regenerating scale and also the fact that the dorso-ventral diameter regenerates at a faster rate than the antero-posterior diameter.

Formation of Ridges in Regenerating Scales.

The number of ridges along the antero-posterior axis of the regenerating scales are recorded in table 20. There were no ridges on the scale after 8,10 and 13 days of regenerating time (fig. 54). At 17 days there were 2 ridges and from then on the number of ridges increased fairly regularly up to 8 ridges at 59 days (fig. 55); By referring to fig. 45. the number of ridges on the regenerating scale may be correlated with the regeneration rate of the antero-posterior diameter. From 10 to 17 days the regeneration rate was quite rapid at which time there were no ridges on the scale and from 17 to 59 days the regeneration rate was much slower and the number of ridges gradually increased from 2 to 8.

The spacing of the ridges is similarly determined by the rate of regeneration. The first ridges that are laid down when the scale is growing rapidly are very wide apart and the ridges are closer together as the scale grows more slowly as it approaches the normal size. A check is formed on the regenerating scale when it completely fills the scale pocket and resumes normal scale growth (fig. 52). The nature of the check varies considerably prosumably depending on the rate of growth of the fish at the time. In some cases there are two or more ridges very closely approximated while in other instances the spacing of the ridges grades more or less insensibly into the normal ridge spacing. Such a check might be useful at any time in determining the size of the fish when a particular injury occurred. Fig. 52 also shows a transference check formed on the scale when the fish was transferred from the St. John Hatchery to the experimental troughs at St. Andrews.

The large focal area of regenerating scales does not possess any ridges but it does have small elevations scattered irregularly over the outer surface. They give this part of the scale a granular appearance and can easily be felt with a fine probe. Therefore the osteoblasts which produce the outer layer of the scale must be irregularly arranged when the regenerating scaler is first being laid down. They do not become regularly arranged around the periphery of the scale to form ridges until the rate of growth of the regenerating scale has slowed down somewhat as has been shown above. Also the first few ridges that are laid down are very wavy and irregular (fig. 52) which is no doubt due to the irregular outline of the young regenerating scale which is quite marked in fig. 54, a scale that has been regenerating for 10 days. This suggests that forking of ridges so often found in normal scales is likely caused by an increased growth rate of that particular part of the scale.

As the osteoblasts, which produce the outer layer of the scale, are found normally only at the periphery of the scale the regeneration of a new scale in the centre of the scale pocket would necessitate either the migration of the osteoblasts to this area or their formation from other cells. Concerning this Neave (1936) states, "It seems likely that the follicle cells play an important part in regenerating scales, for removal of a scale involves also the loss of all or most of the osteoblasts".

Backman (1932) rejects the interpretation of abnormal scales as being those formed to replace scales which have been lost. From one salmon he examined 113 scales from the side and belly of the fish. He says that 53.1 per cent, 30.9 per cent and 11.5 per cent of these scales were laid down in the 1st, 2nd and 3rd years respectively in the river and that 1.8 per cent, 1.8 per cent and 0.9 per cent were laid down respectively in the 1st, 2nd and 3rd years in the sea. He believes that these proportions show that the abnormal scales cannot be regenerated scales but must be new scales intercalated between older ones. All of the scales on a fish are certainly not laid down at the same time but his results do not show this as it is also definitely known that scales are regenerated and he makes no attempt to distinguish between a regenerated scale and one newly formed. Moreover, he states that the widths of the rings surrounding the focal area of these abnormal scales are much greater than are found in normal scales but he is apparently unaware that regenerated scales also possess widely spaced rings before they reach normal scale growth.

Growth of the Fish during the Experiment.

The fish showed good growth during the 59 days of the experiment. It grew 5 cm. in length, from 22.6 to 27.6 cm., an increase of 22 per cent; the length was measured to the mid-fork of the tail. It might be mentioned in this connection that the total length is very often unsatisfactory for experimental purposes as the tips of the tail are usually somewhat worn by chaffing against the trough. The growth in weight was from 103. grams to 217. grams, an increase of 111 per cent.

The food consisted of slices of herring and the daily temperatures and food-consumption are plotted in fig. 51. The temperature curve shows no definite trend but the food curve shows a steady decrease from August 8 to the end of the experiment which cannot be correlated with temperature. The dates when the fish was removed from the trough, anaesthetized and a scale removed, are marked on the abscissa in fig. 51. Since the intervals of time between these dates decrease from July 17 to September 7, it is quite probable that handling the fish so frequently caused the decreased food consumption from August 8 to the end of the experiment.

All of the scales removed from this fish at the end of the experiment had one or two indistinct ridges at the edge of the scale which were very often incomplete anteriorly. It was first thought that this was a mild form of scale absorption but as it occurred on all of the scales it is no doubt a slowing down or complete cessation of scale growth coincident with the poor feeding exhibited by the fish during the last week or so of the experiment. Of the various scales removed from the living fish only those removed September 4 and after possessed these indistinct ridges so they seem to be quite definitely related to poor feeding (see fig. 51).

Fig. 43 Salmon smolt in experiment N.1 showing ventro-dorsal row of "guide mark" scales and the postero-anterior row where every other scale was removed at time intervals varying from 1 to 9 days. X .3

Fig. 44. How the regenerating scalex (stippled) appeared at the end of the experiment (N1) in relation to adjacent normal scales, the regeneration time of these scales being given in table 20.

Fig. 45. Experiment N 1: rate of growth of antero-posterior diameter of regenerating scales compared with the size of the original scales removed from the same pockets.

Fig. 46. Experiment N 1; rate of growth of dorso-ventral diameter of regenerating scales compared with the size of the original scales removed from the same pockets.

Fig. 47. Experiment N 1; rate of growth of antero-posterior diameter of regenerating scales compared with the average size of the two adjacent normal scales in the same row.

Fig. 48. Experiment N 1; rate of growth of dorso-ventral diameter of regenerating scales compared with the average size of the two adjacent normal scales in the same row.

Fig. 49. Experiment N 1; rate of growth of antero-posterior diameter of regenerating scales (right side) compared with the size of corresponding normal scales from the left side.

Fig. 50. Experiment N 1; rate of growth of dorso-ventral diameter of regenerating scales (right side) compared with the size of corresponding normal scales from the left side.

Fig. 51. Daily temperature and food-consumption in experiment N 1; the longer ordinates on the abscissa denote days when the fish was anaesthetized and a scale removed.

Fig. 52. Regenerated scale showing large focus followed by wide ridges formed during regeneration and narrow ridges (RC) when normal growth commences; RC = regeneration check; TC = transference check.

Fig. 53. A regenerated scale showing the small size of the posterior field and the distortion of the same from the main axis of the scale. X 18.

Fig. 54. Experiment N 1; a regenerating scale (Scale No.21) without any ridges - regeneration time 10 days. X 21.

Fig. 55. Experiment N 1; a regenerating scale (Scale No. 13) with 4-5 ridges - regeneration time 28 days. X 21.

Table 20. Time and date of Removal of Scales from Postero-Anterior line of scales of right side, the Regeneration Time of New Scales, and the number of Ridges on New Scales. (N 1).

Scale No.	Date of Removal	Regeneration Time of New Scales in Days	No. of Ridges of New Scales	Time of Removal
5	July 17	59	8	2.40 p.m.
7	" 26	50	7	12.45 p.m.
9	Aug. 3	42	5	3.47 p.m.
11	" 10	35	6	2.16 p.m.
13	" 17	28	4	3.45 p.m.
15	" 23	22	3	1.24 p.m.
17	" 28	17	2	2.39 p.m.
19	Sept. 1	13	0	1.57 p.m.
21	" 4	10	0	2.10 p.m.
23	" 6	8	0	2.27 p.m.
25	" 7	7		2.16 p.m.
Killed fish	Sept. 14			2.15 p.m.

GENERAL DISCUSSION

Effect of Regenerating Scales on Adjacent Normal Scales

In experiment V 9 10 scales on the right side of the fish opposite the posterior base of the dorsal fin and immediately above the lateral line were removed from their pockets and put back in place again. These scales, however, did not remain and new scales were regenerated in these pockets. The normal scales surrounding these regenerated scales were carefully removed and examined to see if they had any checks which might be attributed to the growth of the regenerated scales. The normal scales adjacent to the area of regenerated scales.were retarded in growth and this shows up on the scales as 1 or 2 narrow discontinuous ridges forming a check. Such a check is shown in fig. 56 which is a photograph of a normal scale immediately anterior to 4 regenerating scales in the same row. The check is followed by several wide ridges so it is quite clear that the growth is retarded mainly or perhaps only during the early stages of scale regeneration, i.e. when the scale is regenerating the fastest. The ninth normal scale posterior to these regenerating scales is shown in fig. 57. The five ridges at the edge of the scale are narrower than the preceding ridges and were laid down during the experiment. At the fifth ridge from the edge of the scale, however, there is no definite check similar to that in fig. 56 indicating that the growth of this scale was not retarded by the rapid growth of the regenerating scales. The normal scales surrounding several isolated, single regenerating scales were examined but no appreciable check was evident on these scales. Apparently then, the definiteness of the check on normal scales depends upon the number of scales which are being regenerated in that vicinity.

In most of the experiments about 50 or 60 scales were removed at the commencement of the experiment. In fifteen of the fish the scales surrounding this area have been carefully examined for checks due to scale regeneration. In an antero-posterior row of scales passing through the regeneration area from 20 to 30 of the anterior and posterior scales were mounted separately1 Dorsal and ventral to the regeneration area the scales were mounted together.

In ten of the fish the normal scales possessed checks due to handling etc. where the checks due to regeneration should appear. These checks confused the issue considerably but nevertheless the checks near the regeneration area did appear to be greater. Two of the remaining fish, namely F 1 and F 5, however, were more satisfactory specimens to work with. At the beginning of the experiment these fish were anaesthetized and evidently handled very carefully for there was no definite check formed on the scale but merely the transition from wide ridges previous to the experiment to narrower ridges during the experiment. Thus, although there was not a check to be confused with the regeneration check, the transition from the wide ridges to the narrow ridges formed a definite indication as to where the regeneration check should be if present. In both of these fish the scales near the regenerated scales showed fairly definite checks in the form of 2 or 3 discontinuous, narrow ridges. The check, however, could not be traced more than 3 scales distant from the regenerating scales. If more scales had been removed it might have affected more distant scales, but apparently the retarding effect of the regenerating scales on the normal scales is quite local.

Another thing that is commonly found in the scales surrounding regenerating scales is scale absorption. It was found in practically all the fish examined although it did occur more frequently in some than in others. The amount of absorption varies considerably; in some scales it is very slight while in others a fair portion of the scale was absorbed. Slight absorption, however, was more commonly found. There was no regularity to it. It might occur locally anywhere around the edge of the scale and in extreme cases the edge was absorbed all the way around. Also the absorption certainly occurred at the time of scale removal. Does this then mean that absorption of the normal scales takes place to supply the fast growing regenerating scales with the necessary materials for rapid growth? We think not. It has been shown that scale absorption takes place when the scales are displaced. And this quite surely is the cause of scale absorption in these cases. Due to the overlapping of the scales it would be very difficult to scrape off a large patch of scales without disturbing the surrounding scales. Also, of course, some of the scales might accidentally be displaced in this operation.

That the absorption of normal scales surrounding regenerating scales is not caused by the regeneration of new scales but by scale displacement can be shown in three of the experiments. In the experiments 1 A 7, 2 A 7 and 1 B 7 the fish were starved to death, the time requiring a little over eight months. Scales were removed at the commencement of starvation and new scales grew in to take their place. If the absorption of normal scales is due to the regeneration of new scales, then the scales of these fish should show more absorption than the scales of fish which had been fed after scale removal. This did not prove to be true. In the antero-posterior row of scales passing through the regeneration area the isolated cases of scale absorption were as follows in the three fish. In 1 A 7 the eleventh and thirteenth anterior scales were slightly absorbed and the fourteenth considerably absorbed; the remaining anterior scales showed no sign of absorption; none of the posterior scales was absorbed. In 2 A 7 the twenty-ninth anterior and the second posterior scales were a little absorbed; the other scales showed no sign of absorption. In 1 B 7 not one of the anterior or posterior scales was absorbed. Some of the normal scales dorsal and ventral to the regenerating scales in the three fish were also absorbed. They showed only slight absorption in 1 A 7 but in 2 A 7 and 1 B 7 the absorption was quite extensive in some of the scales. However, in these cases the same amount of absorption was exhibited in the completely regenerated scales also. This shows clearly that the absorption was not due to the regeneration of new scales for the new scales were already completely regenerated when it occurred. The most probable explanation of the few examples of scale absorption which did occur in these fish would be the displacement of the scales. Since the scales of these starved fish did not show any more indications of absorption than did the scales of well-fed fish, it is quite apparent that normal scales surrounding regenerating scales are not absorbed to supply materials to the regenerating scales. Any absorption which does occur must be considered due to some other cause.

Fig. 56. Scale from fish V 9 adjacent to regenerated scales showing that growth (C) was retarded by rapid growth of regenerating scales. X 18.

Fig. 57. Scale from the same fish as fig. 56 and in the same row of scales but from the 9th pocket posterior to the regenerated scales showing that growth (X) was not retarded by rapid growth of regenerating scales. X 21.

Some Exceptionally Small Regenerated Scales.

When scales are removed from a fish new scales grow in to take their places. These scales grow rapidly at first and in a month or so reach the size of normal scales. During the early stages of regeneration of course these scales are small compared with the normal scales. Although most of the regenerating scales eventually reach the size of normal scales, some of them are retarded in growth and remain small compared with the fully regenerated scales or with the normal scales.

In fifteen of the experimental fish the areas where scales had been previously removed were examined for the presence of these extremely small scales. In 33 per cent of the fish anywhere from 1 to 21 of these small scales were found in an area of about one half a square inch. Except for size the majority of these small scales look exactly like the large regenerated scales; some, though, are distorted into queer shapes while others appear to be parts of a scale; whether they actually grew that way or were broken off in removal is hard to say. The small scales invariably possessed a few ridges less than the large regenerated scales. For example, if there were 11 to 12 ridges on the large scales, there would be 8 or 9 ridges on the small scales. There is usually a slight variation in the size of regenerated scales and it is quite easy to see that this might readily be due to the more rapid growth of the larger ones thus crowding out the smaller ones. But the extremely small scales certainly could not be explained on that basis. The explanation was found when the large regenerated scales were picked out one by one instead of scraping off a large number at a time. Five different examples were found where a small scale was situated beneath the posterior end of a large scale, being completely covered by it except for the posterior tip. Since these scales were definitely associated together the number of ridges in the small and large scales respectively will be given, namely 4 and 7, 4 and 6, 5 and 8, 4 and 5, 9 and 11. Due to the presence of the small scales the posterior ends of the large scales were somewhat stunted in growth. Normally the posterior end of the scale is rounded but in two of the scales it was straight across and in the three others it was indented where the small scale was situated. The shape and relative sizes of the large and small scales may be seen in fig. 58. These two scales were taken from fish A 4. The amount of overlapping is indicated by the epidermis being left intact on the small scale. We can be sure that the small scale represents an additional scale and is not merely the result of crowding by the other scales. For normally one scale does not directly overlap only one scale behind it but the adjacent edges of two scales. Also the pocket containing the small scale was situated directly beneath the pocket of the large scale and was exactly the size of the small scale. It must be assumed in these cases that when the scale was removed two regeneration centres were set up in the same pocket, one anterior and the other posterior; the rate of growth was faster in the anterior regeneration centre and therefore produced the larger scale or else regeneration began earlier in this area; instead of the two scales fusing together and forming one double scale the posterior one grew in under the anterior one in such a way that a second pocket was formed. On the other hand regenerated scales have been found where evidently two such scales had fused together to form one double scale in the same pocket.

The small scales just described all occurred in experimental fish of smolt size and the scale growth consisted of part of one summer only. In the scale samples collected from the adult salmon of the St. John River in 1932 a fair number of small scales were noted and at that time the explanation of the occurrence of such extremely small scales was puzzling to say the least. A few of these will be briefly described. On a salmon 90 cm. in length were found 3 small scales which were regenerated during the smolt stage and possessed 3 years of sea growth including a spawning mark. A 77 cm. salmon had one small scale regenerated during the second summer in the river and showing one year of river growth and 2+years of sea growth. A 78 cm. fish had 2 small scales regenerated the second summer in the sea and showing 1+years of sea growth. A fish 83 cm. in length had 1 small scale regenerated during the first summer in the sea and showing 2+years of sea growth. Finally an 80 cm. fish had 17 small scales regenerated just after the second winter in the sea and showing only a few ridges of summer growth in the sea. The small regenerated scales, therefore, might appear at any time during the life of the fish either in the river or in the sea, i.e. as small parr or large sea salmon. It might be mentioned that in the above scale samples from each of the fish there were normal scales as well as both large and small regenerated scales. By comparing the years of growth on the regenerated scales with the years of growth on the normal scales it is a simple matter to determine the time of scale regeneration. The small regenerated scales show the true age of the fish subsequent to regeneration, and in this respect are similar to the large regenerated scales except that the winter checks are not so distinct. Thus the main distinction between the two types of scales is in size only, the difference in size being due to the fact that the large type occupies the original scale pocket while the small type forms an entirely new pocket.

Fig. 58. Showing shape and relative sizes of two regenerated scales which replaced one lost scale; the small scale was in a separate pocket beneath the large scale with only the dark area exposed. X 21.

Effect of Temperature on Feeding.

As the temperature affects the metabolic rate of a fish, it naturally has a considerable influence on feeding. This was noted in all of the experiments whether the fish were constantly at a high or low temperature or whether they were shifted from one temperature to another. In some cases the food consisted of beef liver and because of difficulties in weighing such a food item, it was considered impracticable to attempt any estimation of food consumption. However, observations on feeding and the rate of growth indicated that the fish at the higher temperatures were feeding somewhat better than fish at lower temperatures. In most of the experiments the fish were fed slices or half-slices of herring and the effect of temperature on feeding can readily be determined. A slice of herring weighed approximately 1 gram.

In the experiments A 2 and B 2, the parr A 2 was always at a temperature several degrees lower than B 2. The mean temperature of A 2 was 8.8° with a minimum of 8.1° and a maximum of 10.0°. In B 2 the mean temperature was 12.0° with a greater variation in the daily temperatures from 9.8° to 17.3°. The mean daily food consumption was 11.5 half-slices of herring for A 2 and 17.6 for B 2. Thus with an average difference of 3° in temperature the feeding at the high temperature was about one and a half times that at the low temperature.

In another set of comparable experiments, similar results were found. In this instance A 4 was constantly at a temperature lower than B 4. In A 4 the mean temperature was 9.0° ranging from 8.2° to 10.6°. The mean temperature of B 4 was 12.2° with a minimum of 9.7° and a maximum of 17.6°. The food consumed per day was 14.6 half-slices by A 4 and 24.9 by B 4, i.e. almost double at the higher temperature.

In some of the experiments the fish were carried over winter and show the effect of temperatures from 0° to 6° on feeding. In experiment S 3 a 221 mm. smolt was fed on a ration-diet from September 27, 1934, to August 9, 1935. The fish was feeding regularly every day until the temperature dropped to between 0° and 1°. The temperature remained below 1° from January 14 to March 16; during these two months the fish was observed feeding only on six different occasions. But it must have been feeding more than observed for it gained 1.2 per cent in weight from February 9 to March 9 and excreta were quite often seen in the trough. The fish fed regularly again after the temperature rose above 1°. Some of the particularly low temperatures at which the fish was seen feeding were as follows: 0.0, 0.5, 0.8, 0.9, 1.5, 1.6, and 1.7°C.

The winter temperatures of all the other experiments were not quite so low, the usual range being between 5 and 6°C. But at these temperatures also, the feeding was greatly reduced whether the fish were fry, parr or smolts. In the fry experiments (A 5-6, B 5-6) the lowest temperatures (5-6°C) were in February and March, and the feeding very intermittent. In April the temperature increased no more than half a degree but was sufficient to induce the fry to more regular feeding. In the parr experiments (A 3-4, B 3-4) a difference between the ration-fed fish and the well-fed fish as to time of feeding was noted. Previous to the month of June the well-fed fish hardly ever ate any of the food when it was thrown in to them whereas the ration-fed fish usually ate a little when being fed. The well-fed fish must have done their feeding some time later in the day for they showed a greater increase in weight during the winter months than the ration-fed fish.

Since there was a gradual rise in temperature in most of the experiments the temperature at which the food-consumption was greatest could be determined fairly well. These temperatures will be referred to as the maximum feeding temperatures. In quite a number of the experiments the fish were ration-fed during part of the time, so it is impossible to determine the natural maximum feeding temperature in such cases. In experiments B 2, B 4 and 2 B 7 both feeding and temperature were uncontrolled. In each case both feeding and temperature increased steadily reaching a maximum sometime in August and thereafter declining. B 2 reached a maximum feeding temperature of 15.5° on August 15, 4 days previous to the maximum temperature of 17.3°, B 4 showed a maximum feeding temperature of 15.8° on August 13, 6 days previous to the maximum temperature of 17.6°. Lastly 2 B 7 had a maximum feeding temperature of 16.2° on August 19, also 6 days previous to the maximum temperature, 18.2°. So the greatest difference in the maximum feeding temperatures of these three fish was only 0.7° and the mean was 15.8°.

The maximum feeding temperatures of five other fish under somewhat different experimental conditions were only slightly lower than the above. In these experiments the feeding was also unlimited but the fish were kept at a low temperature for about one month, shifted to a high temperature for a month, and finally back to a low temperature for about a mohth. W 1 had a maximum feeding temperature of 15.0° on August 3, 14 days previous to the maximum temperature of 15.8°. W 2 had two maximum feeding temperatures, one in August 3 of 14.4° and one on August 8 of 15.9°, the maximum temperature being 16.0° on August 17. W 3 had a maximum feeding temperature of 14.4° on August 3, 14 days previous to the maximum temperature of 15.7°. W 4 had a maximum feeding temperature of 14.4° on August 3, 14 days previous to the maximum temperature of 16.0°. F 8, a saltwater experiment, had a maximum feeding temperature of 13.8° on August 4, 20 days previous to the maximum temperature of 18.0°. The uniformity of these maximum feeding temperatures is quite striking considering that they merely represent the mean daily temperature on the day that the fish ate the greatest amount of food. The mean maximum feeding temperature of these fish, subjected to a sudden rise in temperature, is 14.7° which is 1 degree lower than that found for the three fish subjected to a slowly rising temperature. The mean for all these fish taken together is 1.0°. McKenzie (1934) carried out feeding experiments on cod and found the maximum feeding to be at a temperature around 14°. C.

Since the maximum feeding temperature is slightly lower, when a fish is suddenly changed from a low temperature to a high temperature, than it is when there is a gradually increasing temperature, it is interesting to see if the daily food-consumption is also affected by the sudden change in temperature. For this purpose the mean daily food was divided by the weight of the fish, the resulting factor representing the daily amount of food (in half-slices of herring) consumed per gram of fish. The mean high temperatures in August of fish not subject to a sudden change in temperature were: B 2, 14.0; B 4, 13.0, and 2.B 7, 14.5. The mean high temperatures of fish that were changed suddenly to a high temperature were: W 1, 14.0; W 2, 14.2; W 3, 14.0 and 2 4, 14.2. The temperatures then, are much the same in the two types of experiments. The food-weight factors are as follows: B 2, .23; B 4, .23; 2 B 7, .26; W 1, .22; W 2, .16; W 3, .15; W 4, .12. The fish, therefore, that were not subject to a sudden increase in temperature were somewhat better feeders at the same temperature than the fish that were suddenly shifted to a high temperature. Of the latter fish, moreover, it will be noticed that W 1, an immature female, fed considerably better than W 2, W 3 and W 4 which were mature males. So sexual maturity is also an important limiting factor on feeding.

In the low temperature experiments, A 2 and A 4, the mean temperature from June to September inclusive was about 9.0° and the greatest difference in temperature during this time was about 2.5°. In both A 2 and A 4 the temperature showed a gradual increase from around 8° in June to 10° or a little better on August 19 and thereafter decreased only about 1°. In both cases the feeding increased quite rapidly with the rising temperature reaching a maximum in A 2 during the week when the temperature was highest and about a week previous to the highest temperature in A 4. In both A 2 and A 4 the temperature then dropped about 1° and afterwards remained quite uniformly around 9.5°. Corresponding with this drop in temperature the feeding in both cases declined and kept on declining slightly in A 2 but in A 4 soon afterwards started to increase again. The main point to be noted in the feeding at these low temperatures is that the feeding increases when the temperature is increasing but as soon as the temperature decreases slightly to remain at a uniform level the feeding also decreases even though the temperature is about 5° below the maximum feeding temperature of 15° or so.

Experiments B 2 and B 4 (fig. 30-31) show the relation of feeding to a gradually rising and falling temperature. In both of these fish the feeding increased quite rapidly with the rising temperature, the maximum feeding being at a temperature around 15.5° which occurred about a week previous to the maximum temperature (17.5°). Just after reaching the maximum the feeding took a sudden drop, i.e. while the temperature was still rising above the maximum feeding temperature, and after that the feeding decreased with the falling temperature at about the same rate as it was increasing with the rising temp erature. At equal rising and falling temperatures the feeding was poorer at the falling temperature for the temperature was decreasing at a slower rate than it was increasing and, moreover, the feeding took a dudden drop after reaching the maximum. This may be shown by a few examples. B 2 at a rising temperature of 11° ate 13 half-slices and at a falling temperature of 11° ate only 6 half-slices. Also at a rising temperature of 13° it ate 21 half-slices and at a falling temperature of 13° only 15 half-slices. Similarly B 4 at a rising temperature of 11° ate 15 half-slices and only 8 at a falling temperature of 11°; at a rising temperature of 13° it ate 31 half-slices and only 21 at a falling temperature of 13°.

In figures 17-27 of the W series of experiments the effect of a sudden change from a low to a high or a high to a low temperature on feeding may be seen. W 1 fish was an immature female and it was shifted from a low to a high and then back to a low temperature again. In the first period the low temperature was around 8°, in the second period the high temperature was around 15°, and in the third period the low temperatute was around 9°. The feeding (fig. 23) was much better at the high temperature than at either of the low temperatures but the increase in feeding from the low temperature to the high temperature was not proportionate to the increase in temperature. This is partly due to the sudden increase in temperature and partly to the fact that the maximum feeding temperature was 15° and when the temperature rose above 15° the feeding decreased rapidly. Also the feeding in the last low-temperature period was considerably poorer than in the first low-temperature period (2.4 as compared to 4.6 half-slices per day) even though the temperature was a little over a degree higher (9.1 as compared to 7.7). The poorer feeding in the last low-temperature period is due to the sudden change from a high temperature to a low temperature and also to the fact, as explained previously, that feeding is poorer at a dropping temperature than it is at a rising temperature. In W 2, W 3 and W 4 experiments, the fish were similarly shifted from a low to a high and then to a low temperature. The temperatures were almost identical with those of W 1 experiment and the resulting effects of temperature on feeding (fig. 25-27) were the same except that the feeding was considerably poorer, especially in the last low-temperature period, because these fish were all mature males. W 11 experiment was similar to the above except that the temperature was shifted in a different order, namely from a high temperature to a low and then to a high (fig. 19). The feeding during the initial high temperature period was much better than during the following low-temperature period. But when the fish was changed from the low to a higher temperature there was a slight increase in feeding for about a week, and then as the temperature started to decline the feeding dropped off rapidly. So from this graph it is quite apparent that a slowly rising temperature produces much better feeding than a sudden rise in temperature. Experiments W 9, W 10, W 12 (fig. 17, 18, 20) were similarly to W 11 and show exactly the same effect of temperature on feeding. But W 11 was an immature male and W 9, W 10 and W 12 were mature males and consequently the latter were not feeding as well as the former especially in the last high-temperature period.

In another set of experiments the temperature was uncontrolled but the fish were ration-fed during part of the time. W 8 was an immature female fish which was well-fed for 34 days, ration-fed for 33 days, and then well-fed for 49 days(fig. 10). During the initial well-fed period the feeding was increasing with the rising temperature, the mean temperature being 11.6° and the mean daily feeding 7.8 half-slices. And during the final well-fed period the feeding was decreasing with the falling temperature, the mean temperature being 12.2° and the mean daily feeding only 4.2 half-slices. Even though the mean temperatures in these two periods were almost identical the feeding was much poorer at the falling temperature than at the rising temperature in spite of the fact that the fish was ration-fed for 33 days previous to the period with the falling temperature. In the similar experiment, W 7 (fig. 12), the same results were found but in this case the feeding in the last well-fed period was further reduced by sexual maturity. In experiment W 5 the fish was ration-fed for a longer time, namely 48 days, and still in the following period of 68 days the feeding declined rapidly with the falling temperature (fig. 4). But in experiment S 3 the fish was ration-fed for 316 days and in the following well-fed period of 101 days the feeding showed a general upward trend while the temperature showed a steady downward trend from around 14° to 9° (fig. 6) Also in experiment V 2 the fish was starved for 35 days and in the following well-fed period of 61 days the temperature showed a downward trend from 11° to about 8° but the feeding showed an upward trend for 44 days and then a downward trend for the last 17 days (fig. 32). These are the only two cases that can be cited where a dropping temperature did not retard feeding. But they certainly show that feeding is dependent on the condition of the fish as well as temperature. Hathaway (1927) found that fishes consumed about 3 times as much food per day at 20° as at 10°. When the exposure to 10° extended over several weeks the depression of food consumption due to the cold was not counteracted by acclimatization but rather tended to become more pronounced. The fishes experimented on were _Enpomotus gibbosus_, _Lepomis incisor_ and _Micropterus salmoides_.

The results on the effect of temperature on feeding should be applicable to fish in nature because of the similarity of conditions. In streams the fish are subjected to the seasonal and daily fluctuations in temperature as well as the changes from night to day. In this respect the experimental conditions were quite similar since the experiments were carried out in the open and the water heated by the sun. The daily and seasonal fluctuations are quite evident in any of the temperature graphs and, although the variations between nightly and daily temperatures are not shown, it may be stated that there was a difference of several degrees between morning(9 a.m.)

and afternoon (5 p.m.) temperatures. The fish of course were provided with shelter from direct sunlight but this is also available in nature.

Effect of Sexual Maturity in Male Parr on Feeding.

In the W series of experiments there are three sets of similar experiments. Each set contains one immature parr while the other parr were mature. So in the similar experiments the feeding of the mature and immature parr in corresponding periods may be compared and the effect of sexual maturity on feeding determined regardless of other factors.

In experiments W 9, W 10, W 11 and W 12 the fish were under exactly similar temperature conditions during each of the three periods from June 16 to October 10. W 11 was an immature male and the other fish were mature males. The average food consumption for each of the fish in the various periods is given in the following table.

Periods	I June 16- July 20	II July 21- Aug. 24.	III Aug. 25- Oct. 10	Sex
W 9	5.1	2.5	2.2	♂ Mature
W 10	5.6	2.7	1.6	♂ "
W 11	6.6	4.1	3.2	♂ immature
W 12	8.0	2.2	1.8	♂ mature

In these examples maturity had little or no effect in the first period. In the second and third periods, however, the immature fish (W 11) was feeding somewhat better than any of the mature fish, the difference in the two periods being about the same.

In experiments W 1, W 2, W 3 and W 4 the fish were also under similar temperature conditions in each of the low and high temperature periods. W 1 was an immature female while the other parr were mature males. The average number of half-slices of herring honsumed per day during each of the temperature periods is given in the following table.

periods	I June 15- July 20	II July 21 - Aug. 24	III Aug. 25 - Oct. 10	Sex	
W 1	4.6	7.9	2.4	♂	Immature
W 2	3.0	4.6	0.5	♂	Mature
W 3	4.6	5.6	0.5	♂	"
W 4	5.4	5.3	0.6	♂	"

During the first period maturity had no effect on the feeding. In the second period the immature female (W 1) was feeding slightly better than any of the mature males and in the third period the difference was even greater. That is the retarding effect of sexual maturity on feeding increases with the ripeness of the gonads.

In W 7 and W 8 experiments the fish were at the same temperature, and were well-fed in the first and third periods and ration-fed in the second period. W 7 was a mature male and W 8 an immature female. In the first period maturity had little or no effect on feeding, the average number of half-slices of herring per day being 7.6 for the mature fish and 7.8 for the immature fish. In the third period the means were 3.1 for the mature fish and 4.2 for the immature: so in this period maturity certainly retarded feeding.

In experiment W 6 the fish was a mature male which was well-fed in the first period and ration-fed in the second period. It was fed only 2 half-slices of herring each day during the ration-fed period and at the first of this period it was eating the full amount of food given it but after the middle of the period it would eat only 1 half-slice per day and some days none at all. So sexual maturity apparently affected the feeding of this fish also.

Thus in every comparable case the mature parr ate less than the immature parr. Although the differences may be small, it must be admitted that sexual maturity in male parr retards the feeding. The difference between the effect of maturity on feeding in parr and in adult salmon would seem to be one of degree only. For in experiment D 4 (described elsewhere) a grilse retained in salt water was mature in the fall of 1934 and 1935 and at both times ceased feeding entirely. It is common knowledge that adult salmon entering the river to spawn do not feed at this time. But there has always been the speculation as to whether or not they would feed if they could find suitable food. Certaihly the above facts would lead one to believe that they have no desire to feed at spawning time.

Effect of Temperature and Food on Fish Growth.

Three sets of experiments described previously show the effect of feod and temperature on the growth of the fish in length and weight. Each set of experiments consisted of four combinations of food and temperature as follows: well-fed and high temperature, well-fed and low temperature, ration-fed and high temperature, ration-fed and low temperature. The low temperatures were obtained at a cold spring while the high temperatures were produced by holding this water in troughs to be heated by the sun's rays. So the temperatures were not constant but fluctuated from day to day and show the seasonal variations, but the low temperature fish were always at a lower temperature than the high temperature fish and vice versa.

In the set of experiments, A 5-6 and B 5-6, fry of the year were used and the experiment lasted from October 15, 1934, to September 27, 1935, i.e. 18 days short of 1 year. The low and high temperatures during the fall and winter months are not greatly different but during the summer months the mean low temperature was 9.4^{o} and the mean high temperature 12.3^{o}. In the other two sets of experiments parr were used, a single fish to an experiment. Experiments A 3-4 and B 3-4 lasted for 1 year, from September 27, 1934, to Septmmber 24, 1935. Here, again, there was only a slight difference between the low and high temperatures during the fall and winter months but the mean low temperature was 9.0° and the mean high temperature 12.2°. So actually in these two sets of experiments which lasted for a year there was an effective temperature difference only during the summer months. The other set of parr experiments, A 1-2 and B 1-2, were carried on from June 7 to September 24, 1935, a period of 108 days. The mean low temperature was 8.8° and the mean high temperature 12.0°. Thus in all these experiments the mean low temperature was averaging around 9.0° and the mean high temperature around 12.0°, really not a marked difference yet sufficient to show the effect of temperature on growth.

Both the average lengths and weights in A 5-6 and B 5-6 experiments and the percentage increases in length and weight in the other two sets of experiments were consistent in showing similar results on the effect of food and temperature on growth. The unlimited feeding produced better growth than the ration-feeding whether the fish were at the high temperature or the low temperature. There was a greater difference in growth between ration-fed and well-fed fish at the high temperature than at the low temperature which was due mainly to the better feeding of the well-fed fish at the high temperature. When the feeding was unlimited, the high temperature produced better feeding and better growth than the low temperature. When the fish were ration-fed, however, temperature had just the opposite effect on growth, i.e. the high temperature produced poorer growth than the low temperature. In the ration-fed experiments, A 5 and B 5, which were respectively at low and high temperatures there was no significant difference in growth which, however, cannot be considered contradictory to the above statement because the food was not measured exactly and may not have been the same. At any rate in all the other ration-fed experiments, namely A 1 B 1, A 3 B 3 and also F 5 F 1, where the amount of food was the same, the high temperature did produce poorer growth than the low temperature. This is naturally what one would expect of two fish fed the same amount of food and at different temperatures for the fish at the high temperature has relatively less food to be utilized in growth than the fish at the low temperature because it is living at a higher metabolic rate.

As the fish were weighed at various intervals during the course of the experiments the amount of growth at different temperatures could be determined. In the well-fed experiments A 6 B 6 and A 4 B 4 the lowest temperatures were between 5° and 6.5° from December, 1934, to April, 1935, inclusive. Even at these temperatures there were slight increases in weight. As the water was warmed up during the spring and summer months the growth increased rapidly. The maximum growth, however, did not occur at the same temperatures in these two sets of experiments and the age, or size, of the fish seems to be the determining factor. A 6 and B 6 were 1+ year-old parr and the maximum growth occurred in the month of June and not in August when the temperature was highest. The temperature of A 6 in June was around 8° and in August 9-11°. The temperature of B 6 in June was around 9° and in August 12 - 18°. A 4 and B 4, on the other hand, were 2+ year-old parr and the maximum growth occurred in the month of August when the temperatures were highest. The temperatures in August in A 4 were between 9 and 10.6°, and in B 4 between 11.4 and 17.6°. Also in three other experiments (A 2, B 2, 2 B 7) the fish were 2+ year-old parr and the maximum growth occurred in the month of August when the temperatures were highest. The August temperatures in A 2 ranged from 8.8 to 10°, in B 2 and from 11.2 to 18.3°, and in 2 B 7 from 11.4 to 18.2°. So, although there was a difference of only 1 year in the ages of all these fish, the younger 1+ year-old parr show the best growth at the temperature around 8 or 9° while the 2+ year old parr show the best growth at a somewhat higher temperature.

The effect of temperature on weight growth is also evident in some of the W series of experiments where the fish were held for equal periods at low and high temperatures. In every case the increase in growth was greater at the higher temperature. In W 1-4 the fish were first held at a mean low temperature of 7.8° for 35 days and then shifted to a mean high temperature of 14.1°. The percentage increases in weight were as follows, those at the high temperature being in brackets: W 1 42.0 (52.0), W 2 28.3 (59.3), W 3 40.4 (56.2), and W 4 33.8 (42.9). In W 9-12 the fish were first held at a mean high temperature of 11.5° for 34 days and then shifted to a mean low temperature of

9.0° for 35 days. The percentage increases in weight (those at the low temperature in brackets) were as follows: W 9 43.6 (39.3), W 10 61.0 (36.4), W 11 73.2 (36.6), and W 12 56.4 (20.9). In each of these experiments the higher temperature produced better feeding and better growth.

Some idea of the effect of ration-feeding on weight growth may be seen in experiments W 7 and W 8. The feeding was unlimited during the first 34 days and during the following 33 days the ration consisted of 2 half-slices of herring per day. W 7 increased in weight 47.5 per cent during the well-fed period and only 15.3 per cent during the ration-fed period. W 8 shows even a greater difference for it increased in weight 72.9 per cent in the well-fed period and only 14.5 per cent in the ration-fed period. In both of these experiments, however, the difference in growth is exaggerated by the effect of temperature because the mean temperature in the well-fed period was 11.5° and in the ration-fed period 14.2°.

Complete starvation is accompanied by loss of weight and little, if any, change in length. Temperature is an important factor in determining the rate at which the weight is lost. In experiment V 2 the fish was starved for 35 days at a mean temperature of 11.9° and the loss in weight was 9.8 per cent. In experiments 1 A 7, 2 A 7 and 1 B 7 at a mean temperature of 8.2° the losses in weight for the first 33 days of starvation were respectively 5.8, 5.2, and 7.7 per cent. That is the loss in weight varies directly with the temperature. In the latter experiments the fish were starved to death, the time required being from 243 to 257 days and the loss in weight around 41 per cent. The lengths of two of these fish were exactly the same at the time of death as they were at the beginning of the starvation period but the third fish was 2 mm. longer which may or may not represent an actual increase in length. The mean temperature at which the experiments were carried out was around 7°, and of course at higher temperatures the fish would not have lived nearly as long as they did.

Thompson (1926) showed that both food and temperature affected growth of Gadoid fishes. Fish that were well-fed in an aquarium increased nearly 100 per cent in their growth rate as compared with controls at sea, the temperature being the same in both cases. The period of maximum growth in the aquarium fish was from May to October but even in the winter months considerable advance in size continued to be made, although during March growth fell away to a minimum.

Effect of Temperature and Food on Width and Number of Scale Ridges

This was determined in several experiments by changing the same fish from one temperature to another or from one food diet to another. In other experiments, however, the fish were kept continuously at a high or low temperature and on a ration or well-fed diet. An example of the latter type is the set of experiments A 5-6 B 5-6. These experiments were started in the fall of 1934 with 50 fry at each of the different temperature and food conditions, and were completed in the fall of 1935. The number and width of ridges were determined for the summer growth (1935) only, since it was only at this time of year that effective temperature differences were obtained. The winter temperatures were around 5 and 6°C and a winter check was formed on the scales so the ridges from this check to the edge of the scale were counted and the total width measured. Because of a certain number of deaths and the fact that some scales are not very good for dounting and meausring ridges, the results are based on the following number of fish in each experiment: A 5 27, A 6 39, B 5 8, and B 6 28. The mean number and width of ridges in each of these experiments are given in table 21.

Table 21. Mean Number and Width of Summer Ridges in Experiments A 5-6 B 5-6.

Experimental conditions	Expt. No.	Mean Number of Ridges	Mean Width of 1 Ridge mm.
Low-temp;Ration-fed	A 5	6.56 ± .28	.0191
" ;Well-fed	A 6	8.78 ± .29	.0245
High-temp;Ration-fed	B 5	7.99 ± .46	.0193
" ;Well-fed	B 6	10.57 ± .53	.0245

The number of ridges was affected by food and temperature as follows. Of the well-fed fish, B 6 at the high temperature had more ridges than A 6 at the low temperature. Also in the ration-fed fish, B 5 at the high temperature had more ridges than A 5 at the low temperature. Considering the effect of food, at the high temperature the well-fed fish (B 6) had more ridges than the ration-fed fish (B 5) and similarly at the low temperature the well-fed fish (A 6) had more ridges than the ration-fed fish (A 5). So in these experiments both the high temperature, as compared with the low temperature, and the unlimited feeding, as compared with the ration-feeding, resulted in a greater number of ridges being laid down on the scale. As a matter of fact the number of ridges may be definitely correlated with the size of the fish for both the mean lengths and weights and the mean number of ridges were greatest in B 6 fish, not so great in A 6 fish, less in B 5 fish, and still less in A 5 fish.

The same order, however, is not so apparent in the mean width of ridges in these experiments. Of the well-fed fish, B 6 at the high temperature and A 6 at the low temperature showed exactly the same width of ridges, namely .0245 mm. per ridge. Also in the ration-fed fish, B 5 at the high temperature and A 5 at the low temperature showed practically the same width of ridges, namely .0193 and .0191 mm. respectively. The effect of food on the width of the ridges was as follows: at the high temperature the well-fed fish (B 6) had wider ridges than the ration-fed fish (B 5) and likewise at the low temperature the well-fed fish (A 6) had wider ridges than the ration-fed fish (A 5). As far as the effect of food on the width of ridges is concerned, these mean values quite rightly show that a ratioh-fed fish will have narrower ridges on the scale than a well-fed fish. But on the other hand they would appear to show that the effect of temperature on the width of ridges is the same at the high and low temperatures. The reason for this is quite evident when the number of ridges is plotted against the width of the ridges as in fig. 59.

This figure shows the number of summer ridges and the total width of those ridges from each fish in the several experiments. There was a very good correlation between the number and width of ridges in each of the experiments, the correlation coefficients being A 5 .91 ± .03, A 6 .93 ± .02, B 5 .84 ± .11, and B 6 .97 ± .01. The linear regression lines in the figure were calculated from the regression equation of Y on X. Comparing the effect of food on the width of ridges it is quite evident that well-fed fish A 6 and B 6 had wider ridges than the ration-fed fish A 5 and B 5, Next comparing the well-fed fish, A 6 at the low temperature and B 6 at the high temperature, the fish in B 6 with a small number of ridges have narrower ridges than the A 6 fish while the fish in B 6 with a large number of ridges have wider ridges than A 6 fish. Ther reason for this is clear when it is remembered, as explained elsewhere, that the high temperature produced greater variations in the sizes of fish than the low temperatures At the high temperature the larger fish are more active in preventing or intimidating the smaller fish from feeding. The result is that the smaller fish at the high temperature have produced relatively more and narrower ridges than the smaller fish at the low temperature. That ration feeding at a high temperature produces more and narrower ridges than ration-feeding at a low temperature is evident in a number of experiments. For instance F 1 at a high temperature produced 19.9 ridges with a mean width of .030 mm. while F 5 at a low temperature had 16.6 ridges with a mean width of .040 mm.; likewise B 1 at a high temperature had 7.2 ridges, mean width .020 mm. while A 1 at a low temperature had 6.6 ridges, mean width .028 mm. In table 21 it will now be clear why the ration-fed fish (B 5) at a high temperature produced almost as many ridges as the well-fed fish (A 6) at the low temperature although the width of the ridges was much narrower. So, in the above experiments where the fish were kept continuously under the same experimental condition for several months, the effect of food and temperature on the number and width of the ridges might be summed up as follows: Unlimited feeding produces more and wider ridges than ration-feeding either at a high or low temperature. A high temperature produces more and wider ridges than a low temperature if the food is unlimited but if the food or feeding is limited in any way a high temperature produces more but narrower ridges than a low temperature.

In the remaining experiments the fish were shifted from one temperature to another or from one food condition to another but these will be discussed in the next section on factors producing scale checks.

Considerable variation is found in the effect of food and temperature on the width of the ridges in various fishes. Cutler (1918) found that in *Pleuronectes platessa* and *P. flesus* a high temperature increased sclerite-width but unlimited feeding did not. In Dannevig's experiments (1925) on cod the sclerite-width was greater at the time of lower feeding and lower temperature. Gray and Setna (1931) and Bhatia (1931) found that in rainbow trout unlimited feeding produced wider ridges than limited feeding.

Fig. 59. Number of summer ridges plotted against width of ridges for each fish in experiments A 5-6 and B 5-6 to show the effect of food and temperature on the width of the ridge; A 5 (low temp.; ration-fed); A 6 (low temp; well-fed); B 5 (high temp.; ration-fed); B 6(high temp.; well-fed).

Factors Producing Scale Checks

Scale checks include any degree of narrowing of ridges due to slower growth, narrow or incomplete ridges due to change in growth rate, and any mark due to cessation of growth such as granular appearance of the scale or even scale absorption. They may be broadly classified as annual or winter checks, accessory checks, and spawning checks. The annual checks occur at more or less regular intervals on the scale since they are the result of seasonal changes. They are composed of a number of narrow ridges which are incomplete at the sides of the scale, the width of the ridges usually showing a progressive narrowing in the postero-anterior direction. Accessory checks occur at irregular intervals at almost any time during rapid scale growth and are at times so similar to annual checks that they render age determinations extremely unreliable. The spawning checks are definite breaks in the contour of the scale produced by absorption of the periphery during sexual maturity, the ridges of subsequent growth being at an angle to previous ridges. Such a classification of scale checks may be useful but more important are the various factors responsible for or associated with such checks. Many experiments were specifically designed to determine the effect of changes in the environment on the formation of the scale ridges while other factors could be correlated with ridge formation because of the known life-history of the fish. Since salmon spend part of their lives in the river and part in the sea, experiments were carried out in both fresh and salt water.

The amount of food available is of course one of the primary factors determining growth. Altogether, six experiments were carried out where the fish were fed on a ration diet during part of the time. Two of these were in salt water and four in fresh water. In experiment W 5, the fish was first ration-fed for 48 days and then well-fed for 58 days. The feeding was very good during the first part of the well-fed period but dropped off rapidly with the falling temperature. There were 5 ridges formed during the ration-fed period and 7 during the well-fed peridd(fig. 5). And in general the ration feeding produced narrower ridges than the unlimited feeding. But the feeding was very poor during the last 3 weeks of the well-fed period and consequently the last 2 ridges are not quite as wide as those formed during ration feeding. Also a slight check was formed with the change from ration feeding to unlimited feeding, for the last ridge of the ration-fed period was left incomplete and the first ridge of the well-fed period was laid down very close to it. The sudden change in growth rate apparently initiated entirely new scale growth in place of completing the former ridges.

S3 was a somewhat similar food experiment but was carried on in salt water and the length of the experiment greater. The fish was first ration-fed for 3.6 days, from September 27, 1934 to August 9 1935, and then well-fed for 101 days (August 9 to November 18). The length increment was 18.6 per cent in the ration-fed period and 33.6 per cent in the well-fed period. The scale growth (fig. 7) is represented by 8 narrow ridges during ration feeding and 10 wide ridges during unlimited feeding. The band of narrow ridges produced by ration feeding forms a very definite check on the scale interposed as it is between the wide summer ridges of 1934 (previous to September 27) and the wide ridges of the well-fed period (after August 9) of 1935. Some of the ridges of this food check are incomplete at the sides while quite a number extend right down the sides of the scale. The check as a whole resembles a sea winter check almost perfectly but of course differs from a river winter check in the extent of growth. The water temperatures when this check was being laid down varied from 0.1° during the winter months to 14° in August. It is quite evident then that a so-called winter check might extend way on into the summer if the feeding is very poor.

In the food experiment W 6 there were similarly two periods, in the first period the fish was well-fed for 48 days and ration-fed in the second period of 68 days. The length increments were 16.9 per cent in the first period and only 4.6 per cent in the second period. The effect of the better feeding and growth in the well-fed period is clearly shown on the scales (Fig. 9), for there were 5 wide ridges laid down in the well-fed period and only 2 narrow ridges in the ration-fed period.

In the three remaining food experiments, the time was divided into three periods; the fish were well-fed in the first period, ration-fed in the second, and well-fed again in the third. In experiment W8, the fish was well-fed for 34 days, ration-fed 33 days, and then well-fed for 49 days.

The mean food consumption per day was respectively 7.8, 2.0 and 4.2 half-slices of herring and the weight increments 72.9, 14.5, and 49.5 per cent. In agreement with the feeding and growth in these periods, the scales (Fig. 11) showed 5 very wide ridges for the initial well-fed period, 5 fairly narrow ridges for the ration-fed period, and for the final well-fed period 4 wide ridges and 1 narrow one at the edge of the scale. In the final well-fed period, the feeding was decreasing rapidly with the falling temperature and the feeding during the last week was very poor, which accounts for the narrow ridge at the edge of the scale. Some of the narrow ridges produced by ration feeding were incomplete at the sides of the scale and this band of narrow, incomplete ridges resembles a winter check fairly closely. Somewhat the same conditions have been found by Fry (1937) to produce false annuli in cisco scales. He has correlated the false annuli with cessation of feeding and depression in growth when the fish migrate to the hypolimnion.

Experiment W 7 was exactly similar to W 8 except that the fish was a sexually mature male and for that reason the feeding, fish-growth and scale growth were adversely affected. The results were as follows: mean daily food consumption in initial well-fed period 7.6, ration-fed period 2.0, and final well-fed period only 3.1 half-slices of herring; the percentage weight increments were 47.5 in initial well-fed period, 15.3 in ration-fed period, and 16.2 in final well-fed period. Consequently, the scales showed 4 wide ridges for the initial well-fed period when the feeding and growth were good but only 3 or 4 narrow ridges for both of the following ratio-fed periods when the feeding and growth were poor.

Food experiment F7 was similar to W7 and W8 except that it was carried out in salt water and the fish was a smolt instead of a parr. The fish was well-fed for 39 days, ration-fed for 30 days, and well-fed again for 22 days. The food consumption in these periods was respectively 10.8, 3.8, and 6.2 half-slices of herring per day. The scale growth (Fig. 14) was as follows: 10 wide ridges in the initial well-fed period, 5 narrow ridges in the ration-fed period and 2-3 wide ridges in the final well-fed period. Thus the poor feeding in the ration-fed period produced a band of narrow ridges which forms a fairly definite check. The ridges in this check are quite regular and most of them extend down the sides of the scale.

In experiment F2, the fish died before the experiment was completed, but it is of interest in showing the effect of poor feeding at a high temperature on scale growth. During the first month of the experiment, the temperature was raised fairly gradually from 11° to 17°. The feeding at this time was increasing rapidly with the rising temperature and wide ridges were laid down in the scales. During the next month, the feeding declined very rapidly while the temperature remained between 16° and 17°. The scales were quite noticeably affected. The last 4 or 5 ridges formed on the scales were fairly close together and incomplete at the sides while right at the top of the scales were short, indistinct and disconnected ridges. The check thus formed is quite typical of a sea-winter check. Also the ratio of scale-length to fish-length was very high compared with fish in other experiments so it seems likely that the scales kept on growing after the fish ceased to increase in length.

Temperature is another factor which is very important in any consideration of growth. Eleven experiments were attempted to determine the effectiveness of temperature in producing checks in scale growth. Nine of these were in fresh water and two in salt water. Each experiment was divided into two or three periods and in each period the fish was kept at a higher or lower temperature than in another period. In each period, however, the temperature was not constant but slowly rising or falling as the case might be. This was particularly noticeable in experiment 2 B 7 (Fig. 15) where the fish was at a high temperature from August and shifted to a lower temperature in September and October. The mean temperatures were 12.8° for the high temperature period and 9.2° for the low temperature period. As the temperature was rising from June to August, so also were the percentage weight increments as follows: June 24.6, July 65.1, and August 82.7. At the low temperature, they decreased to 16.6 in September and 7.1 in October. The mean food consumption in the high temperature period was 13.3 slices of herring per day and only 6.2 in the low temperature period. The scale growth may be seen in Fig. 16. There were 12 wide ridges laid down during the high temperature period and 4-5 narrower ridges during the low temperature period. Thus in general the effect of a higher temperature is to produce better feeding and wider ridges. But when a certain limit in temperature is reached, the process is reversed and the higher temperature then produces poorer feeding and narrower ridges. This is noticeable in the high temperature period of this experiment where the feeding was improving rapidly with the rising temperature until the maximum feeding was reached on August 13 at a temperature of 16.2°. After that date, the feeding dropped off rapidly. The maximum temperature of 18.2° was reached six days later. Corresponding with this poor feeding during the last two weeks of the high temperature period, the last 3 of the ridges produced in this period were narrower than the preceding 9 ridges

In four of the temperature experiments, W9 - 12, the fish were kept 34 days at a high temperature, 35 days at a low temperature, and 47 days at a high temperature again. The results of these experiments are given in Table 22, showing the effect of changes in temperature on feeding, growth and width of ridges. For the daily temperatures and feeding see Fig. 17 - 20. The temperatures in all these experiments were practically the same. The mean for the initial high-temperature period was 11.5°, for the low-temperature period 9.0°, and for the final high-temperature period 12.0°. In the first period, the temperature rose gradually from about 9° to 17° and then dropped to 13°. In the second period it increased only slightly from 8.5° to 9.0°. In the third period it rose from 13° to 16° and then dropped to 9°. So the immediate change in temperature from one period to another was a drop of about 4° from the low to the high. The relation between feeding and temperature was as follows: The best feeding was in the first period, increasing with the rising temperature, but was much poorer in the second period when shifted to a lower temperature; with the shift to a higher temperature in the third period the feeding increased only slightly at first, but on the whole was even poorer than at the low temperature, for which the combination of three adverse factors can be given, namely, sudden change in temperature, falling temperature, and sexual matur-

TABLE 22

MEAN TEMPERATURES, FOOD CONSUMPTION, PERCENTAGE WEIGHT INCREMENTS, NUMBER AND WIDTH OF RIDGES IN VARIOUS TEMPERATURE PERIODS OF EXPERIMENTS W9-12.

	Experimental Conditions	High Temp.	Low Temp.	High Temp.
	Length of Periods in Days	34	35	47
W9 Mature Male	Mean Temp.	11.4	8.8	12.0
	Mean Daily Food	5.1	2.5	2.2
	Wt. Increment %	43.6	39.3	28.2
	No. & Width of Ridges	4 Wide	4 Slightly narrower	2-3 Very narrow
W10 Mature Male	Mean Temp	11.6	8.9	12.1
	Mean Daily Food	5.6	2.7	1.6
	Wt. Increment %	61.0	36.4	12.2
	No. & Width of Ridges	3 wide	3 slightly narrower	3 very narrow
W11 Immature Male	Mean Temp.	11.5	9.0	12.0
	Mean Daily Food	6.6	4.1	3.2
	Wt. Increment %	73.2	36.6	34.0
	No. & Width of Ridges	3-4 wide	3 slightly narrower	5-6 Very narrow
W12 Mature Male	Mean Temp.	11.6	9.1	12.2
	Mean Daily Food	8.0	2.2	1.8
	Wt. Increment %	56.4	20.9	12.5
	No. & Width of Ridges	4 wide	3 slightly narrower	2-3 very narrow

ity. Consequently the growth of the fish was similarly affected, showing the best growth in the first period and a progressive decrease in the second and third periods. And likewise there were wide ridges laid down in the initial high-temperature period, only slightly narrower ridges at the low temperature, and very narrow ridges at the final high temperature. In other words, wide ridges are laid down at higher temperatures if the feeding increases proportionately with the temperature, but if the temperature is dncreased and the feeding does not increase, then narrower ridges are laid down. Also, if the temperature is decreased, the feeding decreases and narrower ridges are formed.

In the temperature experiment F4, the precedure was the same as in experiments #9-12 and the age of the fish the same but it was a larger fish already changed into the smolt dress and the experiment was carried out in salt water. It was retained at a high temperature for 46 days, at a low temperature for 31 days, and again at a high temperature for 19 days (Fig. 21). The mean temperatures for the respective periods were 14.1, 12.4, and 16.3. The feeding increased steadily with the rising temperature in the initial high temperature period, took a sudden drop at the beginning of the low temperature period and decreased steadily throughout the remainder of that period and even during the final high temperature peridd. The means for these periods were respectively 10.4, 8.1 and 3.0 slices per day. Corresponding with the good feeding in the initial high-temperature period there were 7-8 wide ridges laid down in the scale (Fig. 22) and with the poorer feeding in the low-temperature period

3-4 narrower ridges which were complete at the sides but nevertheless forming an appreciable check. So far this experiment is in agreement with other similar experiments, but it differs from all the other experiments in that 5-6 fairly wide ridges were formed in the final high-temperature period when the feeding was even poorer than in the low-temperature period. These ridges were wider than those formed in the low-temperature period but not as wide as those formed in the initial high-temperature period. Wider ridges being formed when the temperature is increased and the feeding decreased is an exception to all the other experiments, and although it might possibly be explained in a number of ways, yet the question arises, is it a normal reaction. It would seem not for two reasons. Firstly, because of the rapid and steady decline in feeding from the beginning of the low-temperature period right to the end of the experiment; and secondly because of the development of a white spot on both eyes about a week before the end of the experiment, which is fairly characteristic of dying salmon in salt water.

In temperature experiments W1-4, the procedure was reversed. The fish were first kept at a low temperature for 35 days, then shifted to a high temperature for 35 days, and finally back to a low temperature for 47 days. The daily temperatures and feeding may be referred to in Figs. 23, 25-27. The temperatures were practically the same in all of these experiments and the mean temperatures by periods were: 7;8° initial low-temperature period, 14.1° high-temperature period and 9.2° final low-temperature period. The mean temperatures as well as food-consumption and percentage weight increments are given in Table 23. In each of the experiments, both feeding and weight-growth were somewhat better in the high-temperature period than in the initial low-temperature period and much better than in the final low-temperature period. In fact, the feeding and growth in the final low-temperature period were much poorer than in the initial low-temperature period, even though the temperature was over a degree higher in the former. These facts have been explained elsewhere and need not be repeated here. However, it should be mentioned again that although the feeding increased with the change to a higher temperature, the increase was not proportionate to the increase in temperature. Moreover, during the high-temperature period the feeding was increasing with the rising temperature until the maximum feeding was recorded at a temperature between 14.4° to 15.0°, and as the temperature rose above 15.0° (reaching a maximum of 16.0° two weeks later) the feeding dropped off quite rapidly. The width of the ridges was quite dependent on the relation between feeding and temperature. In experiment W1, 4 ridges were formed in the initial low temperature period, the first two of these next the transference check being narrow and the next two very wide; 5 ridges were formed in the high temperature period, the first two being fairly wide corresponding with the good feeding during the first two weeks of this period, and the next three fairly narrow corresponding with the declining feeding during the last three weeks of the period; 3 ridges were formed in the final low-temperature period and were fairly wide (Fig. 24). Thus the widest ridges were formed during the low temperature period and the narrowest ridges during the high temperature period; and although the difference between the widths of the ridges was not very great, it does show that a check may be formed at high temperatures if the feeding does not increase proportionately with the temperature (similar to 2B7 above). In experiment W2, there were 7-8 ridges formed during the experiment; the first ridge formed part of the transference check, the second was fairly narrow, and the remaining ridges were fairly wide and the widths quite uniform except the last ridge, which was narrower than the others. So the widths of the ridges were practically the same during the initial low and high temperature periods and there were no ridges formed in the final low-temperature period or possibly the last ridge represents this period but the scales removed at the beginning and at the end of this period were so similar that this was hard to decide.

In experiment W3, 9 ridges were formed during the experiment; the first 4 ridges were fairly wide and the last 5 ridges somewhat narrower, the ridge at the edge of the scale being the narrowest. So the ridges formed in the initial low-temperature period were slightly wider than those of the high-tempera ture period, the last narrow ridge on the scale possibly belonging to the final low-temperature period.

In experiment W4, there were about 7 ridges formed in the initial low and high-temperature periods together, the widths being fairly uniform except the first ridge next the transference check was narrower than the others and the last two ridges (especially the last) were slightly narrower than the preceding ridges. There were no ridges formed in the final low-temperature period, for the scales removed at the beginning and at the end of this period showed the same markings. So in this case there was no perceptible change in the width of the ridges when the fish was shifted from the low to the high temperature but narrower ridges were formed at the end of the high temperature period when the feeding dropped off rapidly. In the temperature experiment F8, the same procedure was followed as in the above four experiments except that the fish was in salt water. It was kept at a low temperature for 46 days, at a high temperature for 31 days, and again at a low temperature for 32 days (Fig. 28). The mean temperatures for the respective periods were 11.7°, 16.5° and 11.9°. During the initial low-temperature period, the feeding was increasing proportionately with the rising temperature. The maximum feeding occurred at a temperature of 13.8° in the first day of the high-temperature period when the temperature was raised only about a degree. During the remainder of this period, the temperature was between 16° and 18° and the feeding declined steadily; and there was a sudden drop in feeding with the change to the low temperature. The means for the resp ctive periods were 11.0, 12.4 and 5.0 slices of herring per day. The scales (Fig. 29) showed 9 wide ridges formed in the initial low-temperature period and 10 narrow ridges in the remaining high and low-temperature periods together; the last ridge was the narrowest and the last 2 ridges at the edge of the scale were disconnected. That is, with the change from the low to the high temperature, the ridges became narrower because the feeding in relation to the temperature was relatively poorer; and with the change back to the low temperature again the feeding dropped off at such a rate that the ridges

ridges were of the same width as those formed at the high temperature.

So in the temperature experiments (W1, W2, W3, W4 and F8) where the fish were shifted from a low to a high and then to a low temperature, it is quite evident that the width of the ridges is dependent on the relation between feeding and temperature. With a sudden change from a low to a high temperature, The suddenness of the change adversely affects the feeding so that it increases at a slower rate than the temperature. Moreover, the feeding decreased rapidly at the high temperatures when they rose above 13.8 - 15.0°. Consequently the change from a low to a high temperature in no case resulted in wider ridges at the high temperature but on the other hand some of the ridges were approximately the same width, some slightly narrower and some much narrower than the low temperature ridges, depending on the feeding.

The sudden change from one temperature to another or from one feeding condition to another may or may not produce incomplete ridges on the scale at the time of the change. In Fig. 5 may be seen incomplete ridges when the fish was suddenly changed from ration-feeding to unlimited feeding. At the end of the ration-fed period apparently one or more ridges at the edge of the scale were incompletely formed, and when better growth was initiated by better feeding, the latter ridges were left incomplete and new ridges formed around them. In some cases even the former edge of the scale can be seen as a fairly distinct line between the old and new ridges. In other changes from good feeding to poor feeding, from a high temperature to a low temperature, and from a low temperature

TABLE 23

MEAN TEMPERATURES, FOOD CONSUMPTION AND PERCENTAGE WEIGHT INCREMENTS IN VARIOUS TEMPERATURE PERIODS OF EXPERIMENTS W1-4

Experimental	Conditions	Low Temp.	High Temp.	Low
W 1 Immature Female	Mean Temp.	7.7	14.0	9.1
	Mean Daily Food	4.6	7.9	2.4
	Wt. Increment %	42.0	62.0	24.3
W2 Mature Male	Mean Temp.	7.8	14.2	9.1
	Mean Daily Food	3.0	4.6	0.5
	Wt. Increment %	28.3	59.3	-2.1
W 3 Mature Male	Mean Temp.	7.8	14.0	9.3
	Mean Daily Food	4.6	5.6	0.5
	Wt. Increment %	40.4	42.9	-8.3
W4 Mature Male	Mean Temp.	7.9	14.2	9.3
	Mean Daily Food	5.4	5.3	0.6
	Wt. Increment %	33.8	42.9	-2.3

to a high temperature incomplete ridges may or may not be formed. The same applied whether or not the fish was handled (anaesthetic method only) at the time of the change to remove scales. Also, different scales from the same fish may or may not show incomplete ridges at the time of the change, so it seems to be merely a question of whether or not any of the ridges are incompletely formed at the particular time when the change was made.

A very definite check may be produced on the scale by transferring the fish from one place to another. A large number of two year-old parr and smolts were brought from the St. John Hatchery to St. Andrews (about 70 miles) on May 20, 1936, and all of the fish had checks on the scales due to this trip. These transference checks are shown in Figures 4, 9, 11, 13, 22, 24, 29, 38 and 52. They consist of a very narrow band of closely spaced ridges, in these cases usually 2-4 in number. The ridges were not only very narrow but were also disconnected and irregular, being very indistinct in places, giving the appearance of scale absorption. Checks of a somewhat less definite nature were produced by transferring 1 year-old parr from Joe's Spring to McNichol's Spring, a distance of about half a mile. Also checks, not nearly as distinct as the above, were produced by transferring fry on September 6, 1934 from the Florenceville Hatchery to St. Andrews, a distance of about 110 miles. It might be claimed that these transference checks are produced by the change in environment, change in temperature, change in food or what not, but the weakening of the fish during transference and the slow recovery thereafter would seem to be the most potent factor The fish transferred from St. John to St. Andrews were not in the best of condition because some were afterwards inflicted with fungus growth. Also the fish moved from Joe's to McNichol's spring were weakened in transit because too many were carried in each hatchery-can on a hot day, the oxygen was reduced, and many of the fish died. In the temperature experiments described above, the fish were not taken from one trough and put in another, but the fish, water and trough were moved together from one part of the set-up to another. Consequently the fish were not upset very much or weakened in any way by the transference and a check was not produced on the scale. Moreover, some of the fish were moved around quite frequently from one part of the set-up to another when less care was taken and corresponding checks were seldom produced by the transference. Thompson (1926) transferred Haddock, Codling and Whiting from the sea to experimental tanks. The fish were well-fed but he found that "Two or three weeks were necessary before the fish accommodated themselves to the new conditions, and this check in growth was marked by an apparent ("false") winter mark on the scales in all cases where the transference of fish was carried out during the season of greatest growth."

In experiments A1-2; B1-2; A3-4; and B3-4, very definite checks were produced on the scales at the beginning of the experiments on September 25, 1934. These checks are quite similar to the transference checks, i. e. they consisted of 1-2 narrow ridges, usually surrounded by indistinct, disconnected parts of ridges which have the appearance of slight scale absorption. The cause of the checks was the rough handling the fish received when scale samples and measurements were being taken on the live fish. In these experiments the fish were not anaesthetized to facilitate handling but were enclosed in cheesecloth straight-jackets which were tightened on them until they could be held firmly. The fish would be out of water less than a minute but the struggling evidently weakened the fish sufficiently to upset its normal growth. These fish were handled the same way on June 10, 1935 to take more scale samples and measurements, and again the same type of scale check was produced in all the fish except B 3. This fish was being ration-fed so the ridges were all narrow and no check could be distinguished. It is quite possible, however, that the check formed on June 10, 1935, may mark the end of a so-called winter check as well as a check due to handling. The history of the experiments is as follows. From September 25 to December 10, 1934, the fish were arranged in the summer set-up and the temperature was between 6 and 11°. From December 10, 1934 to May 18, 1935 the fish were arranged in the winter set-up, i.e. all crowded up around the spring and a house built around them, the temperature being 4 - 7°. And from May 18 to September 24, 1935, they were again spread out in the summer set-up (see Fig. 2), the temperature then being between 8 and 17°. Now the interesting thing about the scales was to determine where the winter check ended. But on the scales removed at the end of the experiments (Sept. 25, 1935) the two most prominent checks were those formed on September 25, 1935 and June 10, 1935 which were due to handling. The ridges between these checks were narrower than the ridges following the June 10 check. On June 10 the scales removed from some of the fish had 1 or 2 narrow, incomplete ridges at the edge of the scale while the scales from other fish did not have these narrow ridges at the edge. It is quite evident then that the "handling" check of June 10 appearing on scales removed at the end of the experiment was not all due to handling, in some of the fish at least, because some of the narrow ridges were formed previous to June 10. It was on May 18 that the fish were shifted from the winter to the summer set-up and consequently to a sudden increase in temperature. This would result in a sudden change in growth rate which, as we have seen elsewhere, often produces narrow, incomplete ridges. If this view is correct, it would mean that under certain conditions, the end of a winter check is formed in the spring and not in the fall or winter, but the facts given above are certainly not sufficient to show that this is so. Getting back again to the effect of handling the fish in producing scale checks, it should be pointed out that if the fish are anaesthetized, it is quite possible to remove scales, take measurements, etc. without any check being formed on the scale as a result of the handling. This happened in many of the experiments and it shows that the "handling" check produced when fish are not anaesthetized is due to the weakened or upset condition of the fish after such a struggle.

The twelve parr in the W series of experiments were opened and the sex determined; eight of the fish were mature males, one was an immature male and three were immature females. The large number of mature male parr is not extradorinary but on the contrary it is a common occurrence in Canadian Atlantic rivers. The same thing is found by Dahl (1911) in Norway and by Masterman (1913) in England. Masterman examined the scales of mature male smolts for the presence of absorption or erosion as he calls it, but could not find any. This agrees with our conclusion concerning the mature male parr in these experiments. However, the edges of these scales presented a peculair granular appearance and the last ridge or so was very faint, more so in some places than in others. So it was at first thought that this might represent a slight absorption of only the outer layer of the scale. The edges of the scales from the immature male and the three immature females had exactly the same appearance, so sexual maturity is certainly not directly responsible for this condition. Another mature male parr was taken later in the fall on November 19 and used to fertilize some landlocked salmon eggs. The edges of the scales showed the same granular appearance and indistinctness of the ridges but was no greater in extent than in the above fish.

Since the feeding was very poor during the latter part of all these experiments, it is believed that the absorption-like appearance of the ridges at the edge of the scale is due merely to very poor growth. That is, poor scale growth may be represented by very fine disconnected ridges. This was exactly the appearance of the edges of the scales which were removed from the W fish at the beginning of the experiments and which were described as transference checks. That is, the check at the edge of the scale was not very prominent but consisted of indistinct ridges or more correctly, parts of ridges. But the transference checks (see fig. 4, 9, 11, 24) on the scales removed at the end of these experiments were very prominent because the first ridge or so laid down at the beginning of the experiment was quite distinct and very close to the indistinct, disconnected ridges previously formed. It is the latter ridges which give to these checks the appearance of slight scale absorption. Quite often also the end of a winter check presents a granular appearance of the outer layer of the scale which resembles absorption but in all these cases it would seem more properly interpreted as very poor growth which is insufficient to form distinct ridges. In the scale regeneration experiment N1, indistinct ridges at the edge of the scale could be quite definitely correlated with poor feeding because scales were removed at various times during the experiment. At the end of the experiment, scales were removed from different places on the body of the fish and all of these scales had 1 or 2 indistinct ridges at the edge (Fig. 52). But of the various scales removed from the living fish during the experiment, only those removed during the last 11 days of the experiment possessed these indistinct ridges and it was at this time that the feeding was poorest.

That starvation was an important factor in producing a check on the scale was shown in experiment V2. The fish was starved for 35 days and well-fed before and after the starvation period. The loss in weight was 9.8 per cent and after starvation the weight increased 68.4 per cent in the first month and 27.7 per cent in the second. The feeding was only fair for the first two weeks after the starvation period but in the following six weeks showed rapid improvement. The scale growth consisted of 6 narrow ridges followed by 7-8 wide ridges (fig. 33). The 6 narrow ridges formed a very definite check, some of the ridges being incomplete and some extending all the way down the sides of the scale. The first two ridges of the check were very narrow and incomplete and were possibly formed during the starvation period; the remaining four ridges of the check are not so narrow and were formed during the two weeks' recovery period subsequent to starvation when the feeding was only fair. The wide ridges following the check were formed during the last six weeks of the experiment when the feeding was very good. The starvation check on these scales is quite similar to a winter check except that in the latter, the change from wide to narrow ridges is usually more gradual. The interpretation of only a small part of this starvation check being formed during the starvation period and the greater part when feeding was resumed is based largely on the results of other starvation experiments. For instance, in experiments 1A7, 2A7, and 1B7 the fish were starved for approximately 8 months and not fed again after being starved. In these cases, there may have been one or even two ridges formed on the scale during the starvation period but there was certainly no check as definite or as extensive as the starvation check in V2 experiment where the fish was starved for only 35 days.

Perhaps the most definite check of all is that associated with spawning or rather the onset of sexual maturity (Fig. 36). These so-called spawning marks are formed by the gradual absorption of the periphery of the scale during the ripening of the sexual organs. The absorption begins at the posterior end of the scale and works forward along the edges, both layers of the scale being affected, but usually more of the outer layer is absorbed than the inner layer. In spring and early summer the absorption is only slight and confined to the exposed portion of the scale and part of the ridged portion at the junction of these two areas. Late in the fall at spawning time when the sexual organs are fully developed, the absorption may extend all the way around the periphery of the scale and be so extensive as to wipe out the previous winter check and even part of the previous summer's growth. During this time, the fish apparently voluntarily ceases feeding but when the spawning act is over and feeding resumed, the new ridges of scale material laid down are not parallel with the old ridges, due to unequal absorption at anterior and posterior ends of the scale, thus leaving a definite and characteristic mark on the scale. Quite characteristic also are the ridgeless areas of the old scale which are not filled in by subsequent scale growth. Because of the slow recovery after such a prolonged fast, in some cases over a year (Huntsman, 1936), the first few ridges following the spawning mark are usually quite narrow and in this respect are comparable with the narrow ridges of the starvation check in experiment V2 which were produced in the two weeks' recovery period following a starvation period of 35 days. Scale absorption was also found associated with splenectasis in an experimental fish (F2, Fig. 38) and in a fish from Roper Brook, Cape Breton Island. This type of absorption, however, is not likely to be confused with spawning absorption for several reasons. There are great variations in the extent of the absorption on different scales from the same fish; some scales are extremely absorbed, some only slightly and some not atall. Also the absorption might appear locally anywhere around the periphery of the scale without other areas being in the least affected. On the other hand, spawning absorption is always progressively less, going along the margin of the scale from the posterior to the anterior end and all the the same fish are approximately affected to the . The only other type of scale absorption which we have found was that due to the displacement of a scale in its pocket and for the same reasons this might also be distinguished from spawning absorption, although not so readily.

Scale displacement was attempted in experiment V9 to determine the various types of checks that might be produced in that way. A 263 mm. smolt was anaesthetized and from one area on the body, 10 scales were removed from their pockets and then replaced, and in another area the skin was rubbed sufficiently to loosed the scales without removing them. At the end of two months, the fish had increased in length 6.1 per cent and these scales were then examined. The 10 scales that had been removed and put back in the pockets evidently did not remain for these pockets contained only regenerated scales. In the area where the skin was rubbed, the scales showed various types of checks, depending presumably on the amount of displacement. The most noticeable check is shown in Fig. 41. This scale was absorbed all the way around the edge and included both layers. Surrounding the absorbed edge are 3 or more ridges of new growth. The check thus formed resembles a spawning mark except in the regularity of contour and the absence of ridgeless scars so characteristic of spawning marks. Some scales were absorbed only at the posterior edge others only at the anterior edge while still others showed only slight absorption of the outer layer only. The latter type was not as definite as the other checks and an example is shown in fig. 42. Whether such slight checks show true absorption or not is really difficult to determine, because the absorption-like appearance might possibly be due to indistinct ridges left incompleted by new growth after slight displacemant. Apparently the scales were not distorted very much in their pockets but in many of them the new ridges formed after the check were not parallel with the old ridges. So the two most prominent features of a displacement check besides apparent distortion are scale absorption and the irregularity of the direction of the new ridges in relation to the old. Displaced scales were quite frequently observed in scale collections of adult salmon from various New Brunswick rivers but, as would be expected, were more frequently found in experimental fish. Various degrees of displacement from the main longitudinal axis have been noted and various degrees of absorption. And although the entire edge may be absorbed, it more frequently happens that only the sides and posterior end are absorbed. It would appear then that the cells involved in scale absorption are those situated at the periphery of the pocket and the edges of the displaced scale that are not in contact with the periphery of the pocket are therefore not absorbed. If this view is correct, it is quite easy to understand why a scale dislodged but not displaced sideways may have absorption all the way around the edge and why a scale displaced sideways and posteriorly would have absorption at the sides and posterior end but not at the anterior end.

Scale checks are also often found on regenerating scales. In the scale regeneration experiment N1, it was shown that the rate of regeneration was very rapid during the first 17 days and no ridges were formed, but from 17 to 59 days the rate of regeneration was much slower and the number of ridges gradually increased from 2 to 8. The width of these ridges is likewise determined by the rate of regeneration. The first ridges that are formed when the scale is growing rapidly are very wide but the widths decrease gradually with the decreasing rate of scale growth as the scale approaches the size of normal scales. A check is usually formed on the regenerating scale when it completely fills the scale pocket and resumes normal scale growth (Fig. 52). However, the nature of the check varies considerably, presumably depending on the rate of growth of the fish at the time. In some cases there are two or more very narrow ridges, while in other instances the spacing of the ridges grades more or less insensibly into the normal ridge spacing. Although such checks might be useful in a special investigation to determine the size of the fish when a particular injury occurred, they are in no way confusing in age determination because regenerated scales cannot be used for such purposes.

In a sample of scales from a fish one frequently finds both regenerated and normal scales. Quite often the normal scales exhibit a check or even scale absorption which corresponds with the time that the other scales were lost and regenerated. In the above experiments, about 50 scales were removed at the beginning of the experiment, so in about fifteen of the fish the normal scales surrounding this area were carefully examined at the end of the experiment for the presence of checks due to scale regeneration. The normal scales near the regenerated scales showed fairly definite checks in the form of 2 or 3 discontinuous, narrow ridges.

(fig.56). The normal scales are retarded in growth only during the time when the regenerating scales are growing at the fastest rate, namely, at the commencement of regeneration. The effect, however, is only local because checks were not found on normal scales more than 3 scales away from the regeneration area. Moreover, it depends to some extent on the number of scales that are being regenerated, for normal scales adjacent to a single regenerated scale do not show any appreciable check in growth. The absorption of normal scales that can be correlated with regenerated scales is not produced to supply scale material for the rapidly growing regenerating scales but results from the displacement of these scales at the same time that other scales are completely dislodged from their pockets.

As will be seen, checks can be produced on salmon scales in various ways. But the important thing is whether these checks can be distinguished from winter or annual checks. The latter are the ones used in age determinations and in calculations of fish lengths at different ages, so it is necessary to be able to distinguish them from accessory checks. The winter checks are composed of a number of narrow ridges which are incomplete at the sides of the scale, the width of the ridges usually showing a progressive narrowing in the postero-anterior direction. The river-winter checks differ from the sea-winter checks mainly in having fewer ridges. But the river-winter checks usually have a granular-like appearance at the anterior edge, whereas the sea-winter checks seldom have the granular-like appearance and do not show such a definite break from one year's growth to the next. In fact, it is often very difficult to determine the anterior edge of a sea-winter check. The appearance of the two types of checks would seem to indicate that the fish in the river cease feeding during the winter but in the sea continue to feed to some extent. The st. John salmon, however, fairly frequently have a sea-winter check in the form of a narrow band of only 2 or 3 very narrow ridges, much the same as the river-winter checks. Such a definite sea-winter check is not found in Miramichi salmon and the fish from these two rivers no doubt have different feeding grounds in the sea. Such a view is also favoured by the larger average sizes of the St. John sea year-classes.

Some of the checks produced in these experiments can be distinguished from winter checks but others again cannot. The spawning marks, scale-displacement checks, checks on regenerating scales and checks in normal scales due to regenerating scales should not be mistaken for winter checks. The handling and transference checks were somewhat similar to river-winter checks and would be quite confusing. The check following starvation was quite similar to a sea-winter check. Some of the food and temperature checks were similar to winter checks and some were not, which of course depends on the extent of the change and the relation between the two factors. It is thus possible to have checks formed at any time of the year, which could be confused with the annual winter checks. It is therefore necessary to know which scales give doubtful readings and the best method is to discard such scales. One who believes he can tell the age of any and every salmon he examines is in grave danger of making many errors. Wise judgement in selecting or discarding material would undoubtedly give more accurate results.

Concerning the factors involved in the production of annual zones on the scales of fish, many opinions have been given. The experimental evidence will be briefly reviewed. Thomson (1904) retained a whiting in captivity from May, 1902 until July, 1903. The fish was fed daily but the temperature of the water was uncontrolled. Since there was no evident winter check on the scales, he was of the opinion that it is the amount of food supply, rather than variation in temperature, which causes the formation of annual checks. Cutler (1918) controlled both food and temperature in his experiments on plaice and flounders. Although the experiments were not very successful, he nevertheless concluded that summer and winter bands are due to changes in the temperature of the water in which the animals are living. Concerning food he says, "The amount of food which the fish consumes and its general condition does not affect the production of summer and winter bands: the only effect which poor nutrition seems to have on the scales is a tendency for the production of few sclerites." Van Oosten (1923) studied adult whitefish retained in the New York Aquarium, and found that temperature and sexual maturity assumed primary significance in the formation of annuli. Thompson (1926) found that winter temperatures produced checks on the scales of Gadoid fishes, even though the food supply was plentiful. Gray and Setna (1931) examined scales of rainbow trout (Salmo irideus) fed by hand continuously throughout the year and did not find any well-defined summer or winter zones. This, they thought, eliminated the suggestion that the periodicity of circulus width found in other members of the Salmonoid family (when under natural conditions) is due to an inherent rhythm over which the environment has no control. They also found that fish fed with abundant food form abnormally wide rings, even during the winter months, and fish fed with limited diet develop abnormally narrow rings. They did not control the temperature but stated that it should not be inferred from their experiments that it is without effect. Bhatia (1931a), also working with rainbow trout, came to somewhat the same conclusion. He says, "The chief factor concerned in the formation of broad or narrow 'summer and winter rings' is the abundance or scarcity of food, and not the rise or fall of temperature. Temperature variations may possibly have an indirect effect by causing variations in the production, consumption, or assimilation of food by the fish." Bhatia (1931b) confirmed the above results by a critical study of his material as well as that of Gray and Setna (1931).

Concerning salmon, we have shown that at high temperatures (within certain limits) wider ridges are formed than at low temperatures. Likewise an unlimited food supply produces wider ridges than a limited diet. So as far as these results go, the annual checks produced by salmon living under natural conditions might be the result of either a scarcity of food or low temperatures. The salmon retained over winter at temperatures between 5 and 6° showed a check on their scales even though they were fed continuously. So in this respect the salmon differ from Rainbow trout. Our results are certainly not in agreement with Cutler's conslusion that 'the only effect which poor nutrition seems to have on the scales is a tendency for the production of few sclerites." For the ration-fed salmon produced narrower as well as fewer ridges than the well-fed fish.

Effect of Temperature and Food on the Relation between Scale-length and Fish-length.

The relation between scale growth and fish growth is of particular importance in fishery work in connection with the methods employed in calculating the length of a fish at earlier ages from its scales. Lea (1910) determined lengths of Clupea harengus at different winter bands by assuming linear proportion between scale length and fish length. Lee (1912) however, points out that the lengths calculated on this assumption do not agree with the empiric lengths. Using Lea's material as well as her own she noticed that for corresponding years the total lengths calculated from the scales of old fish were always lower than those calculated from the scales of young fish. This discrepancy she calls "the phenomenon of apparent change in growth-rate." Huntsman (1918) studied the relation of scale length to fish length for several species of fishes. In *Clupea harengus*, *Tautogolabrus adspersus*, *Pseudopleuronectes americanus*, and *Pomolobus pseudoharengus* he found that the antero-posterior diameters of the scales did not grow at the same rate as the body throughout life. In another paper Huntsman (1918) points out that by the use of a "movable curve" cut out of cardboard or wood one can compensate for the differential growth of the scale compared with that of the body and for the difference in the time of origin of the various scales according to size.

Another method of calculating fish lengths from scale lengths was introduced by Fry (1935). He found that the relationship between scale length and fish length could be represented by a straight line by plotting log scale length against log fish length minus the length of the fish when the scales are first formed. This proved true in a number of species of teleost fishes, namely Clupea harengus, Tautogolabrus adapersus and Pseudopleuronectes americanus (data from Huntsman, 1918); Alosa sapidissima (data from Leim, 1934); Gadus callarius (data from Duff, 1929); Coregonus clupeaformis and the lake Huron race of Leucichthys artedi (data from Van Oosten, 1929); and Oncorhynchus nerka (data from Dunlop, 1924). The method is an application of Huxley's (1932) differential growth formula, namely log. y = log b + k log x, where y and x represent the dimensions of the two characters compared, b = a constant describing the intercept on the y axis, and k = a constant describing the slope of the line. In a considerable number of organisms Huxley had shown that this equation represents the relative growth of parts of the animal in the form of a straight line. He points out, however, that the commencement of growth in the two parts must be simultaneous. For instance the equation cannot be applied to the relative growth of organs in an embryo when one organ is formed some time later than the other. In comparing scale growth with fish growth it is for this reason that Fry subtracts the length of the fish at scale formation from the final length of the fish. In the case of Salmo salar Kerr (1939) found the arithmetic relationship between scale-body growth was in the form of a parabola curve and by extrapolation he determined that salmon were 24 mm. in length when scales first appeared. Using his results and plotting fish length minus 24 mm. against scale length or double log paper a straight line was obtained which agrees with Fry's conclusions concerning other species of fishes.

Since the amount of food and temperature of the water in different streams vary considerably, it is necessary to know what effect such environmental factors might have on the relation between scale growth and body-growth. For this purpose four sets of experiments in all were carried out: one on fry (0+ year-old) from the Florenceville Hatchery, one on 1+ year-old and another on 2+ year-old parr from the St. John Hatchery, and the fourth on 2+ year-old smolts from the St. John Hatchery.

The fry experiments, A 5-6 B 5-6, were started on October 15, 1934 and completed on September 27, 1935. The A 5 fry were at a low temperature and ration-fed, the A 6 fry at a low temperature and well-fed, the B 5 fry at a high temperature and ration-fed, and the B 6 fry at a high temperature and well-fed. At the end of the experiment the lengths of the fish were measured from the tip of the snout to the end of the middle ray of the caudal fin, and the lengths of the scales from the focus to the anterior edge; the same measurements were also taken in the other sets of experiments. The scales were taken on both sides of the fish between thelateral line and posterior base of the dorsal fin. The mean scale length for each fish was computed from ten or more scales, equal numbers from each sice. The log scale length on the y - axis is plotted against log fish length minus 24 mm. (length at scale formation) on the x-axis in fig. 60 (and listed in tables 28-31). The best straight line through the points was determined by the method of least squares. That is the constants b and k in the equation, $\log y = \log b + k \log x$, were determined by least squares and the values of log y calculated from this equation for selected values of log x. The constant b is of no particular value in these experiments except for plotting the lines but the value of the constant k is of importance since it describes the slope of the line thus indicating the relative growth of body and scale. When the value of k is 1 the scales and body are growing at the same rate. Values of k greater than 1 mean that the scales are growing at a faster rate than the body and values less than 1 that the scales are growing at a slower rate than the body. In other words the higher the value of k, the faster is the rate of growth of the scales in relation to the growth of the body. The equations are as follows:

A 5-------- $\log y = -2.0286 + .8853 \log x$

A 6 ------- $\log y = -2.1332 + .9441 \log x$

B 5 ------- $\log y = -2.1094 + .9282 \log x$

B 6 ------- $\log y = -2.4175 + 1.0974 \log x$

The values of k are listed in table 24 together with the mean lengths of the fish in each group. The mean fish lengths show the relative rates of growth in the various groups, for all of the fish were of the same length at the beginning of the experiments. As will be seen from this table the value of k is higher at the higher temperature (B 6) than at the lower temperature (A 6) if the fish are well-fed or if they are ration-fed (B 5 and A 5). The k-value is also higher when the fish are well-fed than when ration-fed at either high (B 7 and B 5) or low (A 6 and A 5) temperatures. Moreover it should be noted that there is a correlation between the k-values and the lengths of the fish which means that the scales are growing relatively faster in comparison with body growth in fast growing fidh than in slow growing fish.

Fig. 60. Relation between scale length and fish length in experiments A 5-6 B 5-6; A 5 (low temp. ration fed); A 6 (low temp., well-fed); B 5 (high temp., ration-fed); B 6 (high temp., well-fed).

Table 24. Values of k and Mean Fish Lengths in experiments A 5-6 B 5-6.

Experimental Conditions	Expt No.	No. of Fish	K Values	Mean fish length mm.	Time
Low temp.;rationfed	A 5	31	.885	75.08 ∓ 1.42	Oct.15/34
Low temp.;well-fed	A 6	40	.944	91.12 ∓ 1.84	to
High temp;ration-fed	B 5	15	.928	78.03 ∓ 2.40	Sept.27/35
High temp;well-fed	B 6	28	1.097	99.29 ∓ 3.01	348 days

In the remaining food-temperature experiments on parr and smolts there were only four fish in each set of experiments, each fish being either well-fed at a high or low temperature, or ration-fed at a high or low temperature. The length of the fish and a sample of scale were taken at the beginning and at the end of the experiment so that fish-growth and scale-growth during the experiment sould be determined and compared. However, in some cases the scales removed at the beginning of the experiment from one side of the body were not from the same relative position as scales removed at the end of the experiment from the opposite side of the body. For that reason the differences between the lengths of the scales at the beginning and at the end of the experiment do not accurately represent the growth of the scales during the experiment because the scales from different parts of the body vary in size (Esdaile, 1912 and Dannevig, 1931). But the handling of the fish at the beginning of the experiments produced checks on the scales and the distance from the check to the edge of the scale represents the growth of the scale during the experiment. To determine the relation between scale-growth and fish-growth during the experiment the log length of the scale from the focus to the handling check and from the focus to the edge of the scale have been plotted against the log length (minus 24mm.) of the fish at the beginning and at the end of the experiment respectively. From the line joining these points the k-value has been determined by looking up the tangent of the angle that the line makes with the base line.

The experiments, A 1-2 B 1-2, with 2+ year-old parr were carried out in the summer of 1935 from June 8 to September 24, a period of 108 days. Fish A 1 was ration-fed at a low temperature, A 2 well-fed at a low-temperature, B 1 ration-fed at a high temperature, and B 2 well-fed at a high temperature. The log scale lengths are plotted against log fish lengths in fig. 61. The k-values and percentage length increments of the fish are given in table 25. In this set of experiments the value of k is higher at the higher temperature (B 2) than at the lower temperature (A2) if the fish is well-fed but lower if it is ration-fed (B1 and A 1). Also the value of k is higher when the fish is well-fed than when ration-fed at either high (B 2 and B 1) or low (A 2 and A 1) temperatures. As in the previous experiments there is perfect agreement between the k-values and rate of body growth. Particular attention should be called to the fact that the ration-fed fish B 1 at the high temperature showed poorer growth and a lower k-value than the ration-fed fish A 1 at the low temperature while in the previous set of experiments the ration-fed fish B 5 at the high temperature showed better growth and a higher k-value than the ration-fed fish A 5 at the low temperature. That is the k-value in these cases can be correlated with rate of growth but not with temperature.

Fig. 61. Relation between scale length and fish length in experiments A 1-2 B 1-2; A 1 (low temp.,ration-fed; A 2 (low temp., well-fed); B 1 (high temp., ration-fed; B 6 (high temp., well-fed).

Table 25. Values of k and Percentage Fish-length Increments in experiments A 1-2 B 1-2.

Experimental conditions	Expt. No.	No. of Scales	K Values	Fish-length Increment per cent	Time
Low temp; ration-fed	A 1	13	.98	28.2	June 8/35 to
Low temp; well-fed	A 2	12	1.08	41.8	Sept. 24/35
High temp; ration-fed	B 1	5	.91	19.0	108 days
High temp; well-fed	B 2	3	1.13	45.9	

The experiments A 3-4 B 3-4 with 1+ year-old parr were continued for one year, beginning September 25/34 and ending September 24/35. Fish A 3 was ration-fed at a low temperature, A 4 well-fed at a low temperature, B 3 ration-fed at a high temperature, and B 5 well-fed at a high temperature. The relation between scale growth and fish growth is shown in fig.62, the k-values and percentage fish-length increments being listed in table 26. This set of experiments is in agreement with the previous set except that the ration-fed fish A 3 at the low temperature has a higher k-value than the well-fed fish A 4 at the low temperature. Likewise as in the previous experiments the values of k, with the exception of A 3, can be correlated with the rate of growth of the fish.

Fig. 62. Relation between scale length and fish length in experiments A 3-4 B 3-4; A 3 (low temp., ration-fed); A 4 (low temp., well-fed); B 3 (high temp., ration-fed); B 4 (high temp., well-fed).

Table 26. Values of k and Percentage Fish-length Increments in experiments A 3-4 B 3-4.

Experimental conditions	Expt No.	No. of scales	K Values	Fish-length Increments per cent	Time
Low temp; ration-fed	A 3	11	.89	44.4	Sept.25/34
Low temp; well-fed	A 4	6	.83	99.3	to
High temp; ration-fed	B 3	2	.74	37.8	Sept.24/35
High temp; well-fed	B 4	10	.86	108.1	1 year.

The experiments with 2+ year-old smolts were carried out in salt-water whereas the fish in the previous experiments were in freshwater. The experiments were started on June 19 and completed on September 30, 1936, a period of 103 days. Unfortunately two of the fish died before the experiment was completed. Of the two remaining fish, F 5 was ration-fed at a low temperature and F 1 ration-fed at a high temperature. Fish F 5 had a k-value of 1.45 and increased in length 31.2 per cent while for F 1 the k-value was 1.36 and the fish increased in length 26.3 per cent. That is the ration-fed fish at the high temperature had a lower k-value and showed poorer growth than the ration-fed fish at the low temperature and thus is in agreement with the other experiments.

So from all of these experiments on the effect of temperature and food on the relation between scale-growth and fish-growth the following conclusions seem justifiable.

The effect of temperature is that a high temperature gives a higher ratio of scale-length to fish-length than a low temperature if the feeding is unlimited but a lower ratio if the feeding is limited. The effect of food is that an unlimited supply of food gives a higher ratio of scale-length to fish-length than a limited supply of food whether the temperature is high or low. Apparently the effect of different temperatures and different amounts of food on the scale-length, fish-length relationship is brought about by alterations in the rate of growth of the fish. So it might be said that a rapidly growing fish will have a higher ratio of scale-length to fish-length than a slow growing fish when the rate of growth is determined by temperature or food conditions and it is quite possible that it would apply when growth is determined by other factors. These results thus afford an explanation of Fry's (1937) observations on the ciscoes of Lake Nipissing. In this lake he found that the fast growing fish migrate to deep water earlier than the slow growing fish. In table 27, taken from his paper, a difference may be seen in the actual diameters of the scales of slow growing fish from shallow water and fast growing fish from deep water. At equal ages the fast growing fish have larger scales than the slow growing fish which is what would be expected from the above results on salmon. Duff's (1929) results on cod, however, are not in agreement with the scale-body growth of salmon or ciscoes. He found that "During the period in which the rate of growth of the length of the fish is greatest, the scales are growing at a considerably slower rate than the fish.".

Table 27. Scale diameters of Lake Nipissing ciscoes in scallow and deep water catches, 1934.

Age	Shallow Water diam. mm.	Deep Water diam. mm.
1	3.85	4.02
2	4.97	5.58
3	5.75	6.44
4	6.55	7.30
5	6.30	7.78
6	6.77	8.36
7	7.40	8.43

Table 28. Fish length (minus length, 24 mm., at scale formation) and scale length of fish in Experiment A 5

Fish Length mm. X	Scale Length mm. Y	Log x	Log Y
36	.2254	1.5563	$\bar{1}.3522$
38	.2481	1.5798	$\bar{1}.3945$
39	.2297	1.5911	$\bar{1}.3617$
39	.2602	1.5911	$\bar{1}.4150$
42	.2463	1.6232	1.3909

Table 28 (continued)

Fish Length mm. X	Scale Length mm. Y	Log X	Log Y
43	.2436	1.6335	$\bar{1}$.3874
44	.2451	1.6435	$\bar{1}$.3892
46	.2813	1.6628	$\bar{1}$.4487
47	.2810	1.6721	$\bar{1}$.4487
47	.2911	1.6721	$\bar{1}$.4639
48	.2665	1.6812	$\bar{1}$.4249
49	.2880	1.6902	$\bar{1}$.4594
50	.3088	1.6990	$\bar{1}$.4900
51	.2798	1.7076	$\bar{1}$.4472
51	.2848	1.7076	$\bar{1}$.4548
51	.3159	1.7076	$\bar{1}$.4997
52	.3754	1.7160	$\bar{1}$.5740
52	.3239	1.7160	$\bar{1}$.5105
52	.3016	1.7160	$\bar{1}$.4800
53	.3229	1.7243	$\bar{1}$.5092
53	.3148	1.7243	$\bar{1}$.4983
56	.3541.	1.7482	$\bar{1}$.5490
57	.3392	1.7559	$\bar{1}$.5302
57	.3265	1.7559	$\bar{1}$.5132
59	.3690	1.7709	$\bar{1}$.5670
59	.3493	1.7709	$\bar{1}$.5428
60	.3398	1.7782	$\bar{1}$.5315
63	.3568	1.7993	$\bar{1}$.5527
63	.3798	1.7993	$\bar{1}$.5798

Table 28 (continued)

Fish Length mm. X	Scale Length mm. Y	Log X	Log Y
63	.3283	1.7993	$\bar{1}$.5159
66	.3846	1.8195	1.5855

Table 29. Fish length (minus length, 24 mm., at scale formation) and scale length of fish in Experiment A 6

Fish Length mm. X	Scale Length mm. Y	log X	log Y
44	.2413	1.6435	$\bar{1}$.3820
46	.3160	1.6628	$\bar{1}$.4997
50	.2788	.16990	$\bar{1}$.4456
52	.3443	1.7160	$\bar{1}$.5366
53	.3141	1.7243	$\bar{1}$.4969
57	.3423	1.7559	$\bar{1}$.5340
57	.3131	1.7559	$\bar{1}$.4955
57	.2987	1.7559	$\bar{1}$.4955 4957
60	.3535	1.7782	$\bar{1}$.5490
60	.3477	1.7782	$\bar{1}$.5416
61	*.3710	1.7853	$\bar{1}$.5694
61	.3418	1.7853	$\bar{1}$.5038 5340
61	.3193	1.7853	$\bar{1}$.5031
62	.3506	1.7924	$\bar{1}$.5453
62	.3435	1.7924	$\bar{1}$.~~6243~~ 5366
62	.4207	1.7924	$\bar{1}$.6243
63	.4063	1.7993	$\bar{1}$.6085

Table 29 (continued)

Fish Length mm. X	Scale Length mm. Y	log X	log Y
64	.3833	1.8062	$\bar{1}$.5832
65	.3998	1.8129	$\bar{1}$.6021
66	.4030	1.8195	$\bar{1}$.6053
66	.3837	1.8195	$\bar{1}$.5843
66	.3699	1.8195	$\bar{1}$.5682
67	.3492	1.8261	$\bar{1}$.5428
68	.4288	1.8325	$\bar{1}$.6325
68	.4109	1.8325	$\bar{1}$.6138
70	.3888	1.8451	$\bar{1}$.5898
70	.3697	1.8451	$\bar{1}$.5682
71	.3603	1.8513	$\bar{1}$.5563
72	.4628	1.8573	$\bar{1}$.6656
73	.4333	1.8633	$\bar{1}$.6365
74	.4100	1.8692	$\bar{1}$.6128
76	.4743	1.8808	$\bar{1}$.6758
80	.4268	1.9031	$\bar{1}$.6304
80	.4254	1.9031	$\bar{1}$.6284
81	.5508	1.9085	$\bar{1}$.7412
84	.4520	1.9243	$\bar{1}$.6551
85	.4513	1.9294	$\bar{1}$.6542
87	.5401	1.9395	$\bar{1}$.7324
89	.4540	1.9494	$\bar{1}$.6571
92	.6135	1.9638	$\bar{1}$.7882

Table 30. Fish length (minus length, 24 mm., at scale formation) and scale length of fish in Experiment B 5.

Fish Length mm. X	Scale Length mm. Y	log X	Log Y
39			
39	.2060	1.5911	1.3139
43	.2565	1.6335	1.4082
44	.2667	1.6435	1.4265
47	.3074	1.6721	1.4871
47	.2806	1.6721	1.4487
48	.2927	1.6812	1.4669
52	.3033	1.7160	1.4814
53	.2951	1.7243	1,4698
58	.3358	1.7634	1.5263
58	.3576	1.7634	1.5539
60	.3480	1.7782	1.5418
61	.3645	1.7853	1.5611
64	.3627	1.8062	1.5599
65	.3724	1.8129	1.5705
71	.3789	1.8513	1.5786

Table 31. Fish length (minus length, 24 mm., at scale formation) and scale length of fish in Experiment B 6

Fish Length mm. X	Scale Length mm. Y	Log X	Log Y
55	.2810	1.7404	$\bar{1}$.4487
57	.3339	1.7559	$\bar{1}$.5237
59	.3845	1.7709	$\bar{1}$.5843
59	.3060	1.7709	$\bar{1}$.4857
60	.3157	1.7782	$\bar{1}$.4997
60	.4137	1.7782	$\bar{1}$.6170
63	.3543	1.7993	$\bar{1}$.5490
66	.4101	1.8195	$\bar{1}$.6128
67	.3555	1.8261	$\bar{1}$.5514
67	.3333	1.8261	$\bar{1}$.5224
67	.3956	1.8261	$\bar{1}$.5977
67	.3998	1.8261	$\bar{1}$.6021
70	.3890	1.8451	$\bar{1}$.5899
71	.3995	1.8513	$\bar{1}$.6021
72	.4115	1.8573	$\bar{1}$.6149
73	.4701	1.8633	$\bar{1}$.6721
73	.4037	1.8633	$\bar{1}$.6064
77	.4599	1.8865	$\bar{1}$.6628
80	.4601	1.9031	$\bar{1}$.6628
80	.4850	1.9031	$\bar{1}$.6857
90	.5952	1.9542	$\bar{1}$.7745
90	.5228	1.9542	$\bar{1}$.7185

Table 31 (continued)

Fish Length mm. X	Scale Length mm. Y	log X	log Y
94	.5478	1.9731	1.7388
97	.5674	1.9868	1.7536
102	.5986	2.0086	1.7774
102	.6065	2.0086	1.7825
108	.6262	.20334	1.7966
108	.6771	2.0334	1.8306

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SUMMARY

A number of experiments have been described showing the effect of food, temperature and other factors on scale growth, and the relation between scale and body growth under different food and temperature conditions. The material consisted mainly of hatchery fish.

Temperature was found to have considerable effect on feeding. At mean temperatures of 9° and 12°C. the food-consumption was almost twice as great at the higher temperature. Feeding was very intermittent at temperatures between 0° and 6° but one fish was observed feeding even at zero degrees. The upper temperature limit of feeding was not determined but the temperature of maximum feeding was around 16° when the temperature was raised gradually and 15° when raised suddenly. Also a slowly rising temperature produced better feeding at a given temperature than a sudden increase in temperature. Feeding increased with a rising temperature but when the temperature decreased slightly to remain at a uniform level the feeding also decreased even though the temperature was about 5° below the temperature of maximum feeding. At equal rising and falling temperatures the feeding was poorer at the falling temperature. As a rule the feeding decreased when the temperature was decreasing but with unlimited feeding following starvation or a long period of ration-feeding the feeding actually increased even though the temperature was decreasing. So the relation of feeding to temperature is to some extent dependent on the condition of

the fish. This was also noticeable in male parr where sexual maturity retarded feeding.

The effect of temperature and food supply on fish growth was determined in several sets of experiments. The mean low temperatures were around 9° and the mean high temperatures around 12°C. Unlimited feeding produced better growth than ration-feeding whether the fish were at the high or low temperature. When the feeding was unlimited, the high temperature produced better growth than the low temperature. When the fish were ration-fed, however, temperature had just the opposite effect, i.e. the high temperature produced poorer growth than the low temperature. Growth in weight was followed throughout the year at various temperatures. The lowest temperatures were between 5° and 6.5° and even at these temperatures there were slight increases in weight. Growth increased rapidly when the water was warmed up during the spring and summer months. The maximum temperatures were in August but the 1+ year-old parr showed maximum growth in June (temperature 8-9°C) while the 2+ year-old parr showed maximum growth in August (temperature 9-18°C).

The effect of temperature and food on width and number of scale ridges was determined by holding fish continuously at a high or low temperature and on a ration or well-fed diet. The results were briefly these. Unlimited feeding produced more and wider ridges than ration feeding either at a high or low temperature. A high temperature produced more and wider ridges than a low temperature if the food was unlimited but if the food or feeding was limited in any way a high temperature produced more but narrower ridges than a low temperature.

In some experiments the fish were subjected to various changes in food or temperature to see if checks could be produced on the scales. It was found that unlimited feeding produced a band of wide ridges, and ration feeding produced a bank of narrow ridges which resembled a winter check. A sudden change from a high to a low temperature resulted in narrower ridges being formed at the low temperature. On the other hand, a sudden change from a low to a high temperature did not result in wider ridges being formed at the high temperature but ridges of the same width, slightly narrower or much narrower depending on the feeding. In most cases the feeding increased only slightly during the first part of the high temperature period and then decreased when the temperature rose above 15^{o}.

Very definite checks have been correlated with the transference of fish from one place to another. These checks usually consisted of a very narrow band of closely spaced ridges which are disconnected and indistinct. Such checks are most likely due mainly to the weakening of the fish during transit and the slow recovery thereafter. Somewhat similar checks were produced by handling the live fish to remove scales etc. These checks were due to rough handling because fish that were anaesthetized and thus handled carefully did not show any checks. Indistinct ridge formation frequently occurs at the end of winter checks and appears much like scale absorption. Reasons are given for believing that it is due to very poor growth.

Quite a marked check was produced by starving a fish for 35 days and then allowing it all it wished to eat. The greater part of this check was interpreted as being formed during unlimited feeding after starvation because other fish were starved until they died and no definite check was formed on the sdales. Moreover, scales from the latter fish did not show any absorption due to starvation so it was concluded that the absorption of scales in spawning fish was not due to fasting during sexual maturity. Scale absorption was also found to be associated with splenectasis. Scale displacement may produce a check in the scales without any absorption or the scales may be extremely absorbed.

A check is usually formed on regenerating scales when they completely fill the scale pocket and resume normal scale growth. Normal scales near regenerating scales show fairly definite checks in the form of 2 or 3 discontinuous, narrow ridges. Normal scales are retarded in growth only during the time when the regenerating scales are growing at the fastest rate, namely at the commencement of regeneration. The effect, however, is only local because checks were not found on normal scales more than three scales distant from the regeneration area. Moreover, normal scales are not absorbed to supply scale material for the rapidly growing regenerating scales.

In respect to the similarily of the checks produced in these experiments to the annual or winter checks the following conclusions were drawn. The spawning marks, scale-displacement checks, checks on regenerating scales and checks on normal scales due to regenerating scales should not be misinterpreted for winter checks. The handling and transference checks were somewhat similar to river-winter checks and would be quite confusing. The check following starvation was quite similar to a sea-winter check. Some of the checks produced by varying the food and temperature were similar to winter checks and some were not, depending on the extent to which conditions were varied and the relation between these two factors. It is thus possible to have checks formed at any time of the year which could be confused with the annual or winter checks.

Experiments were carried out to determine the effect of temperature and food on the relationship between scale-length and fish-length. A high temperature gave a higher ratio of scale-length to fish-length than a low temperature if the feeding was unlimited but a lower ratio if the feeding was limited, and an unlimited supply of food gave a higher ratio than a limited supply whether the temperature was high or low. Scale-fish ratios showed a positive correlation with rates of fish growth, i.e. a fast growing fish had a higher ratio of scale-length to fish-length than a slow growing fish.

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