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THE GROWTH-RATE, TEMPERATURE AND SALINITY RELATIONS

of the

GIANT SCALLOP PLACOPECTEN GRANDIS (SOLANDER)

Author

J. A. Stevenson

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Introduction

In continuation of the work that was being undertaken during the summer of 1933, the present investigation into the growth rate and temperature relations of the Giant Scallop, Placopecten grandis (Solander), was conducted at the Atlantic Biological Station, St. Andrews, N. B., during the summer of 1934 for the Biological Board of Canada.

Two fundamental phases of the problem (Numbers 1 and 2 of the following list) have received special attention; and, in addition, several minor phases that have suggested themselves during the course of the major investigation have been studied. The problem has consisted of the following sub-divisions:

1. A study of the growth rate of adult scallops in different localities and hence differing environmental conditions, along the eastern coast of Canada.

2. The developmental rate and temperature relations of the larval stages, studied by laboratory methods.

3. Verification of the validity of the rings of growth upon the shells of adult scallops as a criterion of growth rate.

4. Normal and abnormal development of larvae under varying salinity conditions.

5. Lethal temperatures of adult scallops (male and female), trochophores and spermatozoa.

6. Behaviour of trochophores under laboratory conditions.

7. Two parasites found attacking scallop eggs.

The work was done during the months of July and August, which at St. Andrews is the height of the spawning season of the scallops. Material was collected for examination at Wilson's Beach (where a number of shells were obtained for a study of the growth-rings) and by dredging for the living scallops in Letang Harbour and elsewhere. From the living specimens obtained in this way, eggs and sperm were obtained in large quantities, though at somewhat irregular intervals, for the study in the laboratory of the developmental rate under varying constant temperature conditions.

II. Growth rate of Adult Scallops

During the summers of 1932 and 1933, samples of scallops large enough for a statistical study of the rings of growth upon their shells were received from a number of widely distributed points along the eastern coast of Canada, and examined. Evidence has tended to show that though there may be a large number of concentric rings upon these shells, certain of them are much more distinct than the rest, and that the manner of spacing of these distinct rings in one sample of shells does not vary much from shell to shell. This and other facts have led us to believe that these rings are annually dposited and can hence, in those shells that show them most clearly, be taken as a criterion of the amount of growth of the scallops in any year of their life. Upper or convex valves have been used exclusively throughout all the measurements that have been made since they show these rings more clearly in most cases than the lower or flat valves. During the summer of 1934, two additional samples of scallop shells from two hirtherto unconsidered localities have been examined. They are as follows:

Sample 1. 100 scallop shells, constituting a portion of the commercial catch for the winter of 1933-34 at Campobello Island, N.B., dredged by fishermen at the Wolves and off White Horse Island near the northwest end of the bay of Fundy. Taken during the spring of 1934 in water ranging from about 10 to 25 fathoms depth with a bottom of sand and stones. These scallops are evidently some of those that were reported by Captain A. E. Moore during the summer of 1931 when he was in charge of the scallop survey with the "Nova IV". He reported them then as being too small for commercial exploitation; but apparently they have since attained sufficient size to be marketed, though they were still at the time of capture, comparatively small. Practically all belonged to an age group with six growth rings.

Sample 2. 7 scallops, all very well marked, constituting the pick of about two dozen shells that were dredged from the Biological Board boat "Delphine" on July 27, 1934, at the inner end of Big L'Etete Passage. Depth 25-40 fathoms, bottom sand and stones; a considerable current was present over the bottom at this place. Owing to the small size of this sample, the averages of measurements taken on the shells cannot be regarded as significant; but since these measurements showed good correlation from shell to shell, they are included here for what they are worth.

Of the three primary methods for the determination of growth rate in mollusca (viz., the age-group method, the annual-ring method and the experimental field method), only one can be applied to these two samples - the annual-ring method. Measurements were made both of the whole shells and of the distances between

adjacent annual rings, and the results averaged and compared with the averages for the other localities considered previously (1932 and 1933). They can perhaps be best compared by tabulation and the drawing of graphs. Since none of these scallops were alive when measured, relationships of weight and volume must necessarily be omitted, and a comparison made only with regard to measurements of length, width and depth. Except for the sample of shells received in 1932 from Mahone bay, N. S., the relationship in any scallops so far considered between length and width has been approximately the same for all localities; and since length is the most convenient for study, width can be disregarded. Depth has been found to vary so extensively within every sample in which it has been possible to measure it that it too can be disregarded at the present time for comparative purposes. The measurement of the distances from the umbo of the various rings of growth in a scallop gives an indication of the length of that scallop at the time at which the ring was deposited since, at that time, the ring was at the free edge of the shell. Assuming the rings to be annual, from this can be deduced the age of the scallop at the time it attained the "legal" length of four inches. Table I and figure I show a comparison of the various samples hitherto considered in this respect.

(In previous reports an estimate of the age-limit of scallops for any one area has been made. In this investigation, however, Sample I was obviously composed almost exclusively of scallops belonging to one age group, which were comparatively young; while in Sample 2, there were not sufficient shells to make an estimate. Hence this phase has been omitted).

Table I. Average lengths of scallops for different regions at the times of deposition of the first nine rings of growth. Upper valves. Lengths in millimetres.

Locality	1st Ring	2nd Ring	3rd Ring	4th Ring	5th Ring	6th Ring	7th Ring	8th Ring	9th Ring	No. of shells examined
Mahone bay, N.S.	22.5	52.0	80.1	103.1	119.7	132.1	140.5	146.7	151.2	200
Mutton bay, P.Q.	19.2	43.3	69.7	92.6	109.9	123.8	133.8	139.9	145.3	100
Grand Manan, N.B.	15.7	47.1	77.4	94.5	107.1	116.6	124.4	130.5	134.9	200
L'Etang, N.B.	16.4	34.9	54.6	71.9	86.5	99;9	111.4	120.6	127.6	42
Carleton, P.Q.	16.1	37.4	61.1	81.0	95.3	105.7	113.6	119.2	123.4	59
Gaspe. P.Q.	16.8	40.2	62.8	78.9	91.2	101.3	110.2	119.9	127.8	100
Digby, N.S.	23.2	50.7	76.4	95.5	108.9	118.5	123.7	131.2	135.4	101
The Wolves, N.B.	20.5	48.2	75.0	96.1	109.2	116.7	124.2	--	--	100
L'Etete, N.B.	19.8	50.8	80.0	101.5	118.4	130.5	142.5	152.4	159.3	7
Average for Whole	18.9	44.95	70.8	90.5	105.1	116.1	124.9	132.5	138.1	909

From this table and an examination of figure 1, it can be seen that, whereas the scallops taken from the Wolves and White Horse Island corresponded in their rate of growth exceedingly closely with those from Grand Manan and Digby, those from the inner end of L'Etete Passage showed a growth rate comparable only in its speed with those of Mahone bay, Nova Scotia. Both results are interesting, particularly the former, because the number of shells examined render the averages quite significant. The Wolves, the Eastern Islands off Grand Manan (where the Grand Manan samples came from) and the deep water in the bay of Fundy from five to fifteen miles west of Digby all apparently produce scallops of the same type. The conditions in all three places - barring depth - are apparently much similar; since the trend of flow of water in the bay of Fundy causes the same water to pass consecutively over the Digby beds, those at the Wolves and those off Grand Manan. It is probable, then, that depth as a factor in growth rate may be disregarded since the Grand Manan scallops were taken in water as shallow as five fathoms, whereas the Digby specimens were not taken in water of less than thirty to thirty-five fathoms.

It is apparently in the most secluded places, such as L'Etang Harbour, where there is not much current at any time to increase the supply of food per definite period of time, that the slowest growth takes place. Belding (1) found that the amount of current present over beds of the Bay scallop (Pecten irradians Lamarck) determined to a great extent, indirectly, by its effect upon the magnitude of the food supply, the rate of growth of these mollusca in Massachusetts; and the same rule seems to apply to the giant scallop. It is in a place like the inner end of L'Etete Passage, where there is, especially at half-tide, a strong current of water flowing over the scallops, that the greatest growth rate is found in the giant scallop. We have not yet had opportunity to investigate the scallop beds in Mahone bay with this in mind, but we suspect that a somewhat similar condition is to be found over them. It is hoped that more scallops from L'Etete can be procured and examined in the future in order to render the average figures more significant.

Whereas Wolves' scallops attain the legal size when they have about 4¼ rings of growth on their shells (= 4¼ years old, assuming the rings to be annual), those from L'Etete apparently attain it with only 3¾ rings (= 3¾ years, similarly).

A comparison of the rate of growth per individual ring between the scallops from these nine localities gives a clear indication of the variations in growth rate they undergo during their life. Table II and figure 2 represent the amount of growth that has taken place for the first nine rings from the time one ring has been deposited until the time the following one appeared.

Table II. Average addition in length of scallop shells from different localities per ring of growth. Upper valves. Measurements in millimetres.

Locality	1st Ring	2nd Ring	3rd Ring	4th Ring	5th Ring	6th Ring	7th Ring	8th Ring	9th Ring	No. shells examined
Mahone bay, N.S.	22.5	29.5	28.1	23.0	16.6	12.4	8.4	6.2	4.5	200
Mutton bay, P.Q.	19.2	24.1	26.4	22.9	17.3	13.9	10.0	6.1	6.4	100
Grand Manan, N.B.	15.7	21.4	30.3	17.1	12.6	9.5	7.8	6.1	4.4	200
L'Etang, NB.	16.4	18.5	19.7	17.3	14.6	13.4	11.5	9.2	7.0	42
Carleton, P.Q.	16.1	21.3	23.7	19.9	14.3	10.4	7.9	5.6	4.25	59
Gaspe, P.Q.	16.8	23.4	22.3	16.1	12.3	10.1	8.9	9.7	7.9	100
Digby, N.S.	23.2	27.5	25.7	19.1	13.4	9.6	7.2	5.5	4.2	101
The Wolves, N.B.	20.5	27.7	26.8	21.1	13.1	7.5	7.5	--	--	100
L'Etete, N.B.	19.8	31.0	29.2	21.5	16.9	12.1	12.0	9.9	6.9	7
Average for Whole	18.9	26.0	25.8	19.8	14.6	11.0	9.0	7.3	5.7	909

It can be seen from this table and the curves in Figure 2 that both L'Etete and Wolves' scallops, judging from these samples, attain their greatest growth between the first and second rings, which would correspond to the second year of growth, assuming the rings to be annual. In this respect they agree with all the others considered except Carleton, L'Etang, and Mutton bay. However, in the L'Etete specimens, growth rate is sustained remarkably, corresponding in this way most closely to L'Etang. The Wolves' scallops apparently keep their growth rate almost exactly equal to that of the scallops from Digby and Grand Manan.

Length-Width Relationship. The relation between the lengths and the widths of the scallop-shells, both from the Wolves and from L'Etete Passage, shows nothing unusual. Table III constitutes two series - one from either place.

Table III. Length-width relationships of scallop shells from the Wolves and L'Etete Passage, N.B. Measurements in millimetres. Upper Valves.

Wolves																	Length
96	99	99	88	96	96	98	101	104	102	104	107	112	111	115	114	115	114
94	99	100	92	95	97	99	104	105	104	108	111	111	114	118	117	114	Width 115
L'Etete																	
109	122	124	128	140	145	149	-	-	-	-	-	-	-	-	-	-	-
114	128	129	133	153	154	158	-	-	-	-	-	-	-	-	-	-	-

As in all other samples hitherto examined, in general the length and width are approximately equal in one animal, with a tendency for the width to exceed the length as the scallop grows larger. This tendency is perhaps a little more marked than usual in the L'Etete scallops, as it is also in those from Mahone bay; but as yet insufficient specimens have been obtained from L'Etete to make general statements.

Figure 3 shows the curves resulting from the measurements in Table III. It can be seen that the relation between length and width varies little and that the curve is almost linear.

Length-Hinge-Line Relationship.

Table IV. Length-Hinge-Line Relationships in scallop shells from the Wolves and L'Etete Passage. Mahone bay and Grand Manan scallops have been included for comparison. Upper valves. Measurements in millimetres.

Wolves																	
100	112	104	101	100	111	109	105	102	110	98	109	115	104	103	93		Length
45	49	41	42	36	46	48	44	40	50	38	45	45	44	42	43		Hinge-Line
L'Etete																	
109	122	124	128	140	145	149	-	-	-	-	-	-	-	-	-		Length
53	54	56	62	69	68	69	-	-	-	-	-	-	-	-	-		Hinge-Line
Mahone bay																	
106	110	117	118	121	121	126	131	136	143	144	145	145	145	150	136		Length
46	60	54	61	54	61	68	68	74	61	79	70	76	73	79	70		Hinge-Line
Grand Manan																	
94	99	100	102	109	118	127	131	131	137	138	141	143	93	90	86		Length
41	42	44	42	44	47	57	58	58	66	59	54	58	39	37	39		Hinge-Line

It can be clearly seenfrom Figure 4, which corresponds to table IV, that there is considerable variation in this relationship. For comparative purposes, Mahone bay and Grand Manan scallops have also been included, constituting what appears to be the two extremes in this respect. As with rate of growth, the Wolves' scallops most closely approximate the Grand Manan ones in possessing a hinge-line on the whole relatively short in comparison to their length; whereas the few L'Etete specimens examined again fairly closely approximate those from Mahone bay. This relationship between the total length of the shell and the length of the hinge-line is in itself purely of scientific interest. However, it appears from the examination of specimens so far that the greater the growth-rate of the scallops (e.g. Mahone bay and L'Etete), the longer in proportion is the hinge-line. This, however, can only be said with reservation as yet, since L'Etang scallops, which gow quite slowly, have much the same length-hinge-line ratio as those from Grand Manan, the latter being scallops with a growth-rate that at times is fairly high.

III. Verification of the Validity of the Rings of Growth as a Measure of Yearly Growth

The evidence that has hitherto been accumulated during the investigation of the growth of adult scallops strongly supports the view that the more definite rings upon the shells are deposited annually, and but once a year, during the winter time. This, however, has not yet been proven definitly. There are two direct methods of verification:

1. The experimental method, in which marked scallops are kept over a period of at least one year, under approximately natural conditions, and examined from time to time to note the time at which the rings appear.

2. The statistical method, in which regular large samples of shells all taken from the same place, are obtained and examined carefully over a period of at least one year, and the approximate time noted at which the greatest number in any one sample deposit their rings.

Since regular large samples are somewhat difficult to procure from one place throughout the year near St. Andrews, the first method is so far the only one that has been used. The experiment is not yet complete. A strong box was constructed at the Biological Station with a doubtle wall of wire netting at either end to allow the free passage of water through it when submerged; and in it were placed, on a floor of gravel, thirty-eight scallops obtained by dredging at L'Etang harbour. Each scallop was nicked with a file at the edge opposite the umbo. The animals used were all apparently quite healthy and ranged over

a considerable extent in size. The box was anchored on the bottom of the St. Croix river on August 30th in about five fathoms; and it is to be left there for the winter, to be examined in the spring after (presumably) the scallops have deposited their "annual" ring.

IV. Growth of Larval Scallops under Laboratory Conditions

Introduction. The months of July and August at St. Andrews constitute the height of the spawning season of Placopecten. Spawning extends into September but at that time it is not nearly so active as it is earlier. Both male and female scallops, resting upon the bottom, discharge their gametes into the surrounding water where fertilization takes place. Where the numbers of scallops are great, as on scallop beds, the union of a sufficient number of sperm with enough eggs is assured; but in places where scallops are scarce, the efficiency of the process is necessarily considerably reduced since the eggs very soon sink to the bottom and eventually die if not fertilized. The present investigation was carried on during the time when the scallops on the L'Etang beds were spawning; and it was found that the best way in which to obtain the sperm and ova in large quantities was to dredge for the adult scallops and keep them until they discharged their genital products in vast masses into the water of the tubs in which they lay. It is apparent that, like a number of other marine molluscs at St. Andrews (Battle, 2), the giant scallop spawns periodically, the time of actual spawning corresponding to the time just subsequent to the new moon (spring tides). Hence, in considering the acquisition of scallop eggs and sperm, this was borne in mind, with the result that these were obtained in more than sufficient quantity, albeit at intervals of about one month's duration. At such times, the scallops were dredged and placed in tubs on the boat; and either the vibration of the boat, the release of water-pressure, or the slight increase in temperature or light caused them, generally in about an hour's time, to throw their genital products which were then collected. In order to obtain fresh ova and sperm, several precautions were taken to delay the spawning of the molluscs till as late as possible so that, as soon after they were shed as possible, the gametes could be placed in the experimental jars. This was accomplished to a certain extent by constant changing of the water in the tubs to reduce the temperature and by shielding from the light. Also, in order that the exact time of mixing of the sperm with the ova could be determined, the male and female adults were segregated in separate tubs. To reduce polyspermy to a minimum, the water in the tubs was diluted considerably where male and female gametes were together, and only small amounts of water containing sperm were added to the tubs containing ova.

As soon as the boat arrived at the Biological Station wharf the tubs were taken to the laboratory and the experiments upon the developing eggs were begun immediatley. Throughout the

developmental experiments the larvae were kept in carefully cleaned pint sealers ("Perfect Seal"), and they were supplied with plenty of fresh oxygen by being placed in water not over one inch deep, which thus had relatively large surface area exposed to the air that was allowed to enter the sealer by means of a cap placed upon it without the rubber band. Also, the water was changed once daily throughout the entire experiments and oxygenated by squirting air bubbles into it with a large medicine-dropper.

Growth of the larvae that were obtained in the above way (artificial fertilization proved to be useless) was studied at different temperatures. Each temperature was maintained practically constant throughout the experiments by the use of a large constant temperature box (see figure 5). This box was divided into a number of compartments separated by zinc partitions and heavily insulated from the outside. At the bottom of one end compartment (E) three electric bulbs supplied heat, controlled by a thermostat in the upper part of the same compartment. The compartment at the opposite end of the box (A) contained a watertight zinc receptacle into which ice could be put. The intervening compartments showed, when an equilibrium had been attained, a range of practically constant temperatures from 2.16°C. in the ice box in A to over 20°C. in E. Only A, B. C and D (2.16°C. to 17.42°C.) were used in the experiments. In each compartment a movable zinc partition was placed horizontally half-way to the bottom (access from the top) and, in all cases, the two small compartments thus produced showed a difference in their mean temperatures, the upper one being about 1.4°C. higher than the lower.

Salinity variations and their effect upon the development of the scallop larvae were also undertaken. Table V summarizes the conditions to which each experimental jar in both temperature and salinity experiments was exposed.

Table V. Summary of laboratory conditions to which experimental pint-selaers containing developing scallop larvae were exposed.

Jar	Salinity per mille	Light Conditions	Max.Temp. °C.	Min.Temp. °C.	Mean Temp. °C.
A_1	30	Dark inside C-T box	3.0	1.5	2.16
A_21	"	"	5.7	4.9	5.26
A_31	"	"	9.4	9.0	9.20
B_1	"	"	10.8	19.6	10;32
B_21	"	"	12.6	12.0	12.34
C_1	"	"	14.7	13.6	14.37
C2	"	"	16.1	15.0	15.52
D1	"	"	17.8	16.9	17.42
F	"	"	14.4	12.5	13.42
		Daylight off wharf at surface.			
A_{11}	27.5	Dark inside C-T box	6.0	4.4	5.06
A_{12}	"	"	9.3	8.4	8.95
A13	"	"	12.5	12.3	12.42
A_{14}	"	"	14.5	13.7	14.20
A_{15}	25.0	"	6.0	4.4	5.06
A_{16}	"	"	9.3	8.4	8.95
A_{17}	"	"	12.5	12.0	12.36
A_{18}	"	"	14.5	13.7	14.20
A_22	20.0	"	5.7	4.9	5.21
A_32	"	"	9.4	9.0	9.24
B_{22}	"	"	12.6	12.0	12.34
C_{12}	"	"	14.6	13.6	14.27
A_23	15.0	"	5.5	5.0	5.26
A33	"	"	9.4	9.0	9.20
B23	"	"	12.6	12.0	12.34
C_13	"	"	14.6	13.6	14.27
A_24	10.0	"	5.5	5.0	5.26
A34	"	"	9.4	9.0	9.20
B24	"	"	12.6	12.0	12.34
C14	"	"	14.6	13.6	14.27
A_25	5.0	"	5.5	5.0	5.26
A_35	"	"	9.4	9.3	9.35
B_25	"	"	12.6	12.3	12.45
C_15	"	"	14.4	13.6	14.0

In changing the water daily in the jars a pipette with a rubber bulb was used. In the early stages of development the scallop larvae sank to the bottom of the jars and it was a simple matter to remove nearly all the super-natant liquid. However, when the trochophores began to swim at all depths, a certain number were inevitably lost at each change of water; and in order that this number might not be too great about half the water only was changed every day. Fresh water was obtained always from the end of the station wharf. The daily temperatures, exchange of water, and examination of samples from the jars, were all done at the same time with each jar, since by this method they remained longest undisturbed in the constant temperature box, hence longest under the intended conditions.

In the microscopical examination, small samples were pipetted from each jar and placed upon a microscope slide. Counts were made, with the aid of a microscope, of the different stages in development and noted on the spot. Largely for sake of convenience the stages were divided and numbered as follows:

Stage 1. Eggs unsegmented, with or without polar bodies
" 2. Early segmentation and blastula
" 3. Gastrula with or without cilia
" 4. Trochophore
" 5. Viliger
A. Abnormally developed larvae
B. Dead larvae

This system has been adhered to throughout all the tables referring to development of the larvae.

Conditions Controlled:

Temperature was controlled over a wide range (2.16 C. - 17.42 C. means) in the different jars, as also was salinity (30 o/oo - 5 o/oo). With regard to light conditions, those experiments conducted within the constant temperature box were in complete darkness except for the few moments when the jars were removed into the subdued light of the basement of the laboratory for examination. A control was run off the end of the station wharf in light conditions exactly equal to those at the surface of the St. Croix river. The supply of oxygen in the jars was maintained by daily changing of the water, by squirting air bubbles into the jars after examination, and by having the water very shallow with relation to its surface area. The only major factor that was not controlled was a food-supply for the Trochophores.

Temperature and Growth of Larvae. A series of eight pint-sealers containing water from the St. Croix River and scallop-eggs just fertilized were placed in the constant temperature box at different temperatures ranging from a mean of 2.16 C. to a mean

of 17.42 C. (see table V). For the purpose of conciseness, the results of only jars A_1, $A_2 1$, B, and C_2 are given and discussed here, since the results for these jars show very well the trend of results for the complete series. The remaining results (for jars $A_3 1$, $B_2 1$, C_1, and D_1) are summarized in tables XXV - XXVII in the appendix and table XV.

Table VI indicates the character of development of scallop larvae that were placed in jar A within the ice-box.

Table VI. Development and survival of scallop larvae kept at a mean temperature of 2.16°C. Maximum temp. - 3.0°C. Minimum " - 1.5°C

Date	August 17	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Hours' Duration	0	1¾	16	40	64	88	112	136	157	184	208	232	256	280	304
Stages 1	100	100	28	35	65	66	52	60	36	37	59	34	19	11	-
2	-	1	1	2	2	3	6	8	13	15	8	4	-	4	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	-	1	-	-	-	1	2	2	2	1	-	-	-
B	-	-	-	-	-	-	-	-	4	-	9	7	28	53	60

This experiment was repeated with essentially the same result. It is clearly seen that at this low temperature, which is probably considerably lower than any met with in the natural habitat, no development took place in the larvae after stage 2. It is possible that a number of the larvae recorded under stage 1 had died and were kept for a time from decomposition by the low temperature. The actual experiment at 2.16°C. was begun at the end of about two hours' development, and it is also possible that any development that had taken place had done so prior to this. At any rate, it can be assumed that little or no development occurs at this temperature which is apparently below the minimum growth-permitting temperature for L'Etang scallop larvae.

It is to be noted that the number of abnormally developed larvae is relatively small in this sample.

In contrast to A_1, jar $A_2 1$, which was placed in the constant temperature box at a mean temperature of 5.26°C. showed very definite development in its larvae. Table VII constitutes the series of counts made upon the larvae in this jar.

Table VII. Development and survival of scallop larvae kept at a mean temperature of 5.26°C. Maximum temp.- 5.7°C. Minimum " - 4.9°C.

	Aug. 6	6	6	7	8	9	10	11	12	13	14	15	16
Hours' Duration	0	3¼	5½	9	33	57	80	104	128	152	176	200	224
Stages 1	100	61	67	70	74	40	20	21	11	2	-	-	-
2	-	9	33	19	16	6	22	34	38	7	-	-	-
3							7	17	56	28			
4							2	6	31	33	1	3	
5													
A			3	10	6	17	8		1	4			
B							3	1	2	10	47	41	42

It was not possible to start this experiment until approximately 5½ hours after fertilization took place. The high rate of growth during the first 5½ hours is hence probably due to the higher temperature (Ca. 12°C.) to which the larvae were subjected. Subsequent to this, however, the rate of growth was considerably diminished and about 80 hours had passed before the appearance of swimming trochophores (stage 4) in the jar. It is to be noted that no development took place beyond stage 4. This was found to be the case in the complete series of experiments, as not one veliger was found in any jar to have developed from the egg. The larvae would remain as trochophores for a greater or less period of time and would then die.

The occurrence of abnormal development was more frequent in $A_2$1 than in A_1; but the two jars cannot be compared for this since it is doubtful if any development at all took place in A_1.

When the number of dead larvae had increased to a considerable extent there invariably appeared in the jars numerous microscopic ciliates that were evidently flourishing upon the decomposing remains.

The span of life of the larvae under the conditions in jar $A_2$1 was approximately nine days. The probable cause of death will be discussed later in this report.

In jar B_1, where the mean temperature was considerably higher than that in $A_2$1, the developmental rate of the larvae was found to be correspondingly greater. Table VIII shows the counts that were made in this jar.

Table VIII. Development and survival of scallop larvae kept at a mean temperature of 10.32°C. Max.temp. - 10.8°C. Min. " - 9.6°C.

	Aug. 6	6	7	8	9	10	11	12	13	14
Hours' Duration	0	5½	9	35	58	82	106	129	153	176
Stages 1	100	67	62	30	8	2			1	
2		33	1	11	37	6				
3				2	20	9	6		2	
4					12	31	37	17	17	
5										
A		3	20	12	8	3				
B				1	2	4	17	41	68	56

The nature of the development of the larvae in this jar is of particular interest in that the temperature conditions closely approximate those of L'Etang Harbour at this time of the year. Hence of all the experiments conducted, this is that which might be expected most to show the natural rate of development in the sea.

As with $A_2 1$, the first 5½ hours of development were at a higher tempeature than during the rest of the experiment due to the fact that the experiment could not be started immediately after fertilization. However, the difference in temperature was in this case only about 2°C.

The trochophore stage was attained in more than a day less than it was at 5.26°C., and developmental rate at the higher tempeature was on the whole considerably greater. The life-span was two days less than at 5.26°C., this being probably due to the higher rate of metabolism and approach of death. Abnormal development had not increased appreciably over the degree occurring at the lower temperature.

The higher the temperature to which the larvae were subjected during their development, the greater the rate of their development. The final example to be discussed here is that of jar C_2 , which was placed in the constant-temperature box at a mean temperature of 15.52°C., about 5°C. above B_1. Table IX refers to jar C_2.

Table IX. Development and survival of scallop larvae kept at a mean temperature of 15.52°C. Max. temp. - 16.1°C. Min. " - 15.0°C.

	Aug. 6	6	7	8	9	10	11
Hours' Duration	0	5½	9	43	63	86	110
Stages 1	100	67	58	11			
2		33	17	13			
3				27			
4				17	2	3	
5							
A		3	5	3			
B				2	22	49	60

The greatly increased rate of development of the larvae over B_1 can at once be seen from the table. The apparent lag in development during the first 5½ hours of the experiment is probably due to the reduced temperature (12°C.) to which the larvae were subjected for a while before the experiment was properly started. The trochophore stage was attained in two days only, and immediately afterwards, evidently due to the high metabolic rate, the trochophores began to die (probably, as in all these cases, because of lack of suitable food-material), the life-span under these conditions being barely four days. Abnormal development was not of frequent occurrence.

Discussion. It is a well-known physiological fact that has been borne out by a great many observations in all the fields of biology that temperature plays a large part in controlling the metabolism and hence growth of living organisms. This is reflected in the nature of the organisms themselves that have been subjected to varying temperature conditions. In general, it may be said that the higher the temperature is, up to a certain point - the optimum for the animal or plant concerned - the more efficient is the metabolism of the animal. Also, there is an upper and a lower limit - the maximum and the minimum for the animal - on the temperature scale, beyond either of which growth does not take place.

In the foregoing experiments upon temperature and its relation to the growth of larval scallops, it is clear that the conditions in jar A_1, as far as temperature was concerned, were below the minimum for these larvae, since no growth took place. However, in jars $A_2 1$, B_1, and C_2, growth did take place very

definitely. Hence the range of mean temperatures 5.26°C. to 15.52°C. was entirely between the maximum and minimum range for these larvae. Jar D_1 was run at a mean temperature of 17.42°C. and, in this jar, definite growth took place; which extends the upper limit of the range considered by 1.90°C.

The minimum temperature to promote growth in these larvae must, therefore, have been between 2.16 and 5.26°C. Judging from the slow growth in jar $A_2 1$, it was not very far below 5.26°C.

The maximum temperature to promote growth in these larvae must also, therefore, have been somewhere above 17.42 C. It is impossible to say how far above it it was since no experiments at higher temperatures were run.

It is impossible from these results to determine the optimum temperature for the scallop larvae with any degree of accuracy at all, since there are no certain criteria by which it can be judged. Chapman (3) has defined the optimum as "the temperature at which there is the least environmental resistance to the biotic potential of the organism . . . .". Since the biotic potential is "the inherent property of an organism to reproduce and to survive, i.e., to increase in numbers", it is impossible, dealing as we are with larval forms that have regularly died before maturity, to determine in any way the biotic potential, and from it, the optimum temperature for development. One can only guess, taking into full account all the data available, at the temperature at which the growth of these larvae appeared to be most healthy. Perhaps the incidence of abnormal growth may be taken as a tentative criterion. Here again we encounter a difficulty in that the largest number of abnormal larvae occurred at mean temperatures of 9.20 C. and 10.32 C. which are surprisingly those very temperatures at which the larvae develop in the natural state in the vicinity of St.Andrews. It is well-known that, with the passage of time, animals and their environment tend towards an equilibrium which comprises the most favourable condition towards the survival and reproduction of the animals concerned. It would, therefore, b expected that in districts where the animals are most plentiful (e.g., scallop beds for scallops) the environmental conditions have, by long trial, proved themselves to be close to the optimum for the animals concerned. Hence it would appear that the occurrence of abnormal larvae in the experimental jars cannot be taken as a criterion of the relative proximity to the optimum of the temperatures considered.

Ignoring the abnormally-developed larvae, however, we do find that at these temperatures (9.20 and 10.32°C. in jars $A_3 1$ and B_1) growth was on the whole quite healthy and the trochophores, when they began to swim, did so with much vigour. At 12.34 C. and upwards, the trochophores were noticed to be somewhat sluggish in their movements.

The very fact that the larvae did all die immediately they had attained the trochophore stage (stage 4) would appear to indicate that death was due to a very definite cause and that

this cause was directly linked with the laboratory conditions. Hence in a discussion on, and in conclusions from the results of the experiments, the death of the larvae should not be taken into account at all. It is clear that they did not die from unfavourable temperature conditions. Conclusion can, therefore, only be drawn from the results referring to the larvae and their development as far as the trochophore stage.

One fact is clear: the higher the temperature, up to 17.42°C. at least, the higher the rate of metabolism of the larvae, although not much difference in their rate of growth was noticed between temperatures of 13°C. and upwards.

Salinity and Growth of the Larvae. In these experiments, four temperatures, covering as wide a range as would be expected to occur in the natural habitat of the scallop during the spawning season, were chosen (Ca. 5.2, 9.0, 12.4 and 14.2°C.) and at each of these temperatures, six jars, containing water of six different salinities (27.5, 25.0, 20.0, 15.0, 10.0 and 5.0 parts per mille) were placed, and the experiments were run concurrently with those discussed previously on temperature. For controls (normal salinity - Ca. 30-75 o/oo) the jars $A_2 1$, $A_3 1$, $B_2 1$, and C_1 which had been placed at the same four temperatures, were used. Thus all salinities considered were sub-normal. Water in the jars was changed daily just as it was changed in the temperature series.

In all, twenty-four jars containing larvae were used and counts made upon all of them. In order to avoid confusion it is proposed to take two definite series from the results accumulated: a series of four jars containing water of the same salinity (sub-normal) but of different temperatures and a series of seven jars at the same temperature but of different salinities. In this way it is possible to obtain a fairly clear idea of the effects of different temperatures upon the growth of the larvae in the presence of water of subnormal salinity; and conversely, the effect of water of varying salinities upon their growth at normal temperature (i.e., that of the sea at St.Andrews).

Series I. Varying temperatures and constant salinity. A salinity of 25 parts per mille will be chosen since it shows characteristic results as well as any other. The four mean temperatures, 5.06, 8.95, 12.36 and 14.20°C., comprise the temperature range. Table X constitutes the results from jar A_{15}. In all the jars in this series, the actual experiment was begun at the termination of 3¾ hours subsequent to fertilization. Hence the counts for the first four hours cannot be taken into account in drawing conclusions from the experiments.

Table X.

Development and survival of scallop larvae kept at a salinity of 25 o/oo, and a mean temperature of 5.06°C.
Maximum temp. - 6°C.
Minimum " - 4.4°C.

	Aug. 17	17	18	19	20	21	22	23	24	25	26
Hours' Duration	0	4	16	40	64	88	112	136	157	184	208
Stages 1	100	100	60	41	37	57	32	20	21	4	
2		1	1	4	7	16	13	18	12		
3							1	1	2		
4											
5					#2						
A				2		2	4	2	3		
B					1	11	6		9	25	60

#Doubtless introduced into the jar as veligers, obtained in mud from L'Etang Harbour.

It is very interesting to note that in this jar, which except for salinity conditions was kept under approximately the same conditions as jar $A_2$1, development did not extend as far even as stage 4, and only just reached stage 3. The percentage of abnormally developed larvae is apparently no greater at the sub-normal salinity than it was in undiluted sea-water.

In jar A_{16}, however, where the salinity was the same as in jar A_{15}, but the temperature increased to a mean of 8.95°C., growth up to the trochophore stage did take place. The number of trochophores present in the jar, however, was not large (table XI).

Table XI. Development and survival of scallop larvae kept at a salinity of 25 o/oo, and a mean temperature of 8.95°C. Maximum temp. - 9.3°C.
Minimum " - 8.4°C.

	Aug. 17	17	18	19	20	21	22	23
Hours' Duration	0	4	16	41	65	89	113	136
Stages 1	100	100	56	29	15	28	3	
2		1	13	8	22	16	1	
3					23	18	1	
4					3	12	1	
5								
A			1	2	7	14	1	
B					3	6	23	32

In table XI, it can be seen that the number of abnormal larvae has increased somewhat over that in table X. However, since this number appears to vary at random at all the temperatures considered, as well as at all the salinities, it cannot be deduced that either temperature or salinity changes have any decided effect upon it.

Taxles XII and XIII consist of the corresponding results of jars kept at mean temperatures of 12. 36°C. (A_{17}) and 14.20°C. (A_{18}). In both of these jars, development reached the trochophore stage and the larvae appeared to be quite healthy, relatively few abnormal specimens being present. As in undiluted sea-water, the higher the temperature was, the higher the rate of development.

Table XII. Development and survival of scallop larvae kept at a salinity of 25 o/oo and at a mean temperature of 12.36°C. Maximum Temp. - 12.5°C. Minimum " - 12.0°C

Aug.	17	17	18	19	20	21	22
Hours' Duration	0	4	17	41	65	89	113
Stages 1	100	100	40	16	3		
2		1	13	15	3		
3				7	13		
4				1	13	4	
5							
A			3	5			
B				1	1	18	28

Table XIII. Development and survival of scallop larvae kept at a salinity of 25 o/oo and at a mean temperature of 14.20°C. Max imum temp. - 14.5°C. Minimum " - 13.7°C.

Aug.	17	17	18	19	20	21
Hours' Duration	0	4	17	40	65	89
Stages 1	100	100	17	18		
2		1	6	14		
3				6		
4				5	14	
5						
A			4	3		
B				4	10	22

Discussion upon Series I of Salinity Experiments:
Irrespective of the salinity in these jars (A_{15} - A_{18}) the influence of temperature upon the developmental rate can be seen quite clearly in a study of Tables X - XIII. As in the first series of experiments, the rate of development varied with the temperature.

The actual salinity of 25 o/oo appear to allow this development at the higher temperatures that were studied, at least. Hence the most obvious way of determining the effect upon development of a lowering of the salinity is to make a comparison between the development under different temperature conditions at both the low and the normal salinities. Jars A_{15}(25 o/oo) and A_{21} (30 o/oo) show a very interesting difference. These jars were kept at approximately identical temperatures and differed appreciably only with regard to salinity. In A_{21} (30 o/oo), development, though slow, proceeded in a healthy manner as far as the trochophore stage and the number of trochophores swimming in the jar was considerable before they died. In A_{15}(25 o/oo),however, there was very definitely an arresting of development from the time stage 2 was reached, and only a very few larvae attained stage 3, while none became trochophores. Since salinity was the only variable major factor in these two experiments, it would appear that the minimum temperature for development is to a certain extent dependent upon salinity and that a slight lowering of the salinity tends to weaken the metabolic processes of the larvae in such a way as to make the latter unable to develop at such low temperatures as they apparently can when the salinity is normal. The minimum temperature may be said to vary inversely with the salinity of the water. That the larvae can develop normally at higher temperatures under such lowered salinity conditions is borne out by the experiments in jars A_{16}, A_{17} and A_{18}. In these three jars development was essentially comparable with that respectively in jars A_{31}, B_{21} and C_{1}. In the case of the two highest temperatures (Ca: 12°C. and Ca: 14°C.), a slight lag in growth rate was detectable at the lower salinity. It is doubtful, however, whether this is of any significance. With regard to the span of life in these two lots of jars, $A_{16}$was a day shorter than its corresponding jar, A_{31}; and A_{16} two days shorter than C_{1}. $A_{17}$was the same as B_{21}. It seems probable that, on the whole, a lowering of salinity tends to weaken the larvae in some way,so that they do not resist the laboratory conditions as vigourously as they do at normal salinity.

Series II. Constant Temperature and Varying Salinities.
A mean temperature of approximately 9.2°C. will be chosen, since it is at about the same temperature that the scallop larvae in the bay of Fundy develop. A series of seven salinities was used in the experiments: e.g., 30, 27.5, 25, 20, 15, 10 and 5 o/oo. These correspond respectively to jars A_{31}, A_{12}, A_{16}, A_{32}, A_{33}, A_{34} and A_{35}. In jars $A_{12}$and A_{16}, the actual experiments began at the end of the first four hours; in all the others, at the end of the first five and a half.

Table XIV. Development and survival of scallop larvae kept at a mean temperature of 9.20°C. and at a salinity of 30 o/oo. Maximum temp. - 9.4°C.
Minimum " 9.0°C.

$A_3 1$

	Aug. 6	6	7	8	9	10	11	12	13
Hours' Duration	0	5½	9	34	57	81	105	128	152
Stages 1	100	67	27	21	12	20	15	4	
2		33	6	7	32	30	5	1	
3						4	3		
4							2		
5									
A		3	19	5	6	8			
B				3		8	59	57	67

Table XV. Development and survival of scallop larvae kept at a mean temperature of 8.95°C. and at a salinity of 27.5 o/oo. Maximum temp. - 9.3°C.
Minimum " 8.4°C.

A_{12}

	Aug. 17	17	18	19	20	21	22	23
Hours' Duration	0	4	16	41	65	89	113	136
Stages 1	100	100	41	26	16	8		
2		1	11	10	13	8		
3					9	16	2	
4					2	10	12	
5								
A				4	2	8	1	
B					2	2	1	20

Table XVI. Development and survival of scallop larvae kept at a mean temperature of 9.24°C. and at a salinity of 20 o/oo. Maximum temp. - 9.4°C.
Minimum " - 9.0°C.

$A_3 2$

	Aug. 6	6	7	8	9	10	11	12
Hours' Duration	0	5½	13	35	58	81	105	129
Stages 1	100	67	42	30	23	24	2	
2		33	11	15	6	11		
3								
4								
5								
A		3	10	18	11	10		
B				3	5	27	58	60

Table XVII. Development and survival of scallop larvae kept at a mean temperature of 9.20°C. and at a salinity of 15 o/oo. Maximum temp. - 9;4°C.
Minimum " - 9.0°C.

A_33

	Aug. 6	6	7	8	9	10	11	12
Hours' Duration	0	5½	13	35	58	82	106	130
Stages 1	100	67	45	38	50	38	9	
2		33	29	9	4	7	3	
3								
4								
5								
A		3	1	8	7	7		
B				3	4	28	49	60

Table XVIII. Development and survival of scallop larvae kept at a mean temperature of 9.20°C. and at a salinity of 10 o/oo. Max. temp. - 9;4°C.
Min. " - 9.0°C.

A_34

	Aug. 6	6	7	8	9	10	11	12
Hours' Duration	0	5½	13	35	58	82	105	129
Stages 1	100	67	54	44	51	36	36	
2		33	10	21	26	14	3	
3								
4								
5								
A		3	4	2	6	9		
B			2	1	1	10	33	51

Table XIX. Development and survival of scallop larvae kept at a mean temperature of 9.35°C. and at a salinity of 5 o/oo. Max. temp. - 9.4°C.
Min. " - 9.3°C.

A_35

	Aug. 6	6	7	8
Hours' Duration	0	5½	13½	35
Stages 1	100	67	9	
2		33	5	
3				
4				
5				
A		3		
B			39	60

Discussion upon Series II of Salinity Experiments. In an examination of the foregoing tables, it is clear that at salinities of 25 o/oo and upwards, development took place, continuing as far as it was ever found to do in the laboratory during the investigation - to stage 4. As with jars containing water of normal salinity, death took place among the larvae upon attainment of this stage.

At a salinity of 20 o/oo and under no development could be detected at all. It is therefore to be assumed that the minimum salinity that promoted the development of these larvae was between 20 and 25 o/oo. Some difficulty was experienced in making the counts in this series of experiments. It was not always easy to distinguish between living and dead larvae belonging to the first two stages, since lack of movement by means of cilia could not be taken as a criterion of death. It is therefore possible that a number of the larvae assigned to stages 1 and 2 were recently dead and had not decomposed enough to show this clearly. The egg-membrane generally burst soon after death allowing the contents to flow out. At the lowest salinity (5 o/oo) this occurred very soon after initial exposure of the larvae to the conditions; but at the higher salinities (15 and 20 o/oo) this did not occur generally for a considerable while, probably due to decreased osmotic pressure; and the eggs may have remained apparently normal for some time after death. Only larvae that were obviously dead were included under stage B.

The first effect of low salinity upon the scallop-larvae as seen with the aid of a microscope was a visible swelling of the ova. The turgor within the cells must have been relatively great, since they increased apparently as much as a half in volume, at the lower salinities bursting quite soon after the commencement of the experiments. One effect of this increased turgor within those larvae that had already, at the beginning of the experiment, undergone the first two or three cleavages, was a definite tendency for the individual cells to break apart; and in the jars where this occurred, spherical cells of all sizes, representing both macromeres and micromers, could be seen. This, too, considerably hindered the making of accurate counts, since it could never be ascertained with certainty whether or not an individual cell was a whole larva or only part of one. In such cases, the free micromeres were disregarded, and the largest "macromeres" taken into account alone.

Food and Growth. Throughout all the experiments upon development under laboratory conditions of the larvae it was found, as I have already stated, that growth persisted in an apparently normal fashion up to a definite stage and at that point ceased. Temperature and salinity were controlled over comparatively wide ranges yet did not influence this result in the least as far as furthering the development was concerned. Oxygen was present in

amply sufficient quantity at all times due to regular changing of the water and the squirting of air into the water at the time of changing. The water itself was obtained from the end of the station wharf and placed in porcelain receptacles previously carefully cleaned; hence the presence of impurities in the water was impossible. Scallop larvae can exist in the water of the St. Croix River (we have taken some in #18 plankton nets), yet when they are placed in a limited supply of the very same water in the laboratory, they die without exception, after having attained the trochophore stage and having remained at it for from one to four or five days. In order to detect any possible effect the necessarily constant light conditions in the laboratory might have had in inhibiting development, a control jar containing precisely the same amount of water and larvae was placed a foot beneath the surface of the St. Croix river at the end of the station wharf. Here it received the natural diurnal alternation of light and darkness. This experiment was repeated to make sure. Table XXI shows the results obtained from this (F) experiment, the two jars giving essentially the same results.

Table XX. Development and survival of scallop larvae kept in a jar placed one foot beneath the surface of the St. Croix river. Max.Temp. 14.4 C
Min. " 12.5°C
Mean " 13.41 C
Salinity - 30 o/oo

	Aug. 17	17	18	19	20	21	22	23
Hours' Duration	0	4	17	41	66	89	113	136
Stages 1	100	100	25	9				
2		1	20	9				
3				9	6	2		
4				6	15	12	11	
5								
A			1	4			3	
B				2			5	26

It can be seen quite clearly that the limit of development, apart from the rate itself, was just the same as it was found to be in the laboratory. The growth rate too, compares favourably with those in jars $B_2$1, and C_1(12.34 and 14.37°C. respectively); hence it would appear that the presence or absence of daylight at this stage in the life history of the larvae is of negligible consequence.

The only major factor likely to influence the growth of the animals is, then, a suitable food supply; and a consideration of the foregoing facts leads us to believe that it is probably

due to an inadequate food supply that death inevitably occurred among the trochophores. During the first stages of its development the larva of a scallop possesses no digestive tract and subsists probably entirely upon the yolk granules present in the macromeres for its food-supply. However, by the time that the larvae has developed the cilia characteristic of the trochophore, the supply of yolk has been depleted. It is at this time that the larva begins to take food externally and at the same time is distinguished by the appearance of a digestive tract. It can thus be seen that, up to the trochophore stage, the larva can develop perfectly normally by itself, other conditions being mormal, without the least necessity of an external food supply. At the time it reaches stage 4, its metabolic processes are very active, as are those of all developing embryos. It it cannot obtain a constant, adequate supply of suitable food thereafter, it is bound to perish. The fact that, in the experimental jars, the trochophores remained generally as such for a few days before finally dying would seem to suggest that they were, during those few days, utilizing the available food supply, such as it was, within the jars. Changing the water regularly once a day no doubt provided them with a certain amount of new food material; but this evidently was not enough to promote their development at normal speed, albeit it probably helped to delay death for some time.

Unfortunately, at the time when it was realized that lack of suitable food material was the probable cause of death, it was too late in the summer to obtain sufficient freshly-spawned eggs upon which to experiment in this regard. A few eggs were obtained and placed in shallow dishes, earlier in the summer, in St. Croix river water to which various possible foods or sources of food had been added. Mud from the lower littoral, green algae and diatomaceous plankton were tried; but no appreciable effect was noted and the eggs that had been obtained were not plentiful enough for the making of counts.

Further experiments will have to be done in this direction before full conclusions can be drawn.

Abnormal Growth. In all jars that were subjected to conditions permitting development at all, and in a few of the low-salinity jars also, a certain number of abnormally developed larvae were found to occur. Just what was the principal factor in determining the nature of development of these individuals, it is impossible at present to say. It is certain that temperature and salinity conditions did not have any bearing since no correlation appears to exist at all between them and the number or nature of abnormal larvae. This is, of course, excepting the instances where at low salinities, due most probably to osmotic pressure and its effects, separation of the cells after cleavage occurred.

Figure 6 shows several of these abnormal forms as they appeared and were drawn under the microscope. It can be seen that, in a large number of the cases, cleavage has taken place successively for a number of times in one plane, thus producing a row of attached cells that may possibly be bent considerably.

Parasites on Eggs and Larvae. During the examination of freshly-shed scallop eggs on August 8th and 17th, two ciliate protozoans were observed that appeared to be parasitic in habit. That seen on August 8th was a species of the genus Lichnophora (identified by means of Pratt's "Manual of Invertebrates"), which is known to be parasitic upon egg masses of Crepidula, and to occur at times upon the exterior of certain adult molluscs.

The other was a species of the genus Trichodina. This genus is well-known as an associate of freshwater Hydrae. In both cases, these protozoans were attached to scallop-eggs in early stages of development by what appeared to be a disc surrounded by a fringe of cilia, and they were constantly revolving on an axis at right angles to the diameter of this disc and passing more or less through its centre, as if they were endeavouring to break through the egg-membranes. They were both watched for about half and hour but were not seen to accomplish this.

That there are very probably parasitic enemies to be dealt with by larval scallops seems to be evident by these observations, and through their occurrence under laboratory conditions at St.Andrews was relatively quite rare, it seems that this can be added as one more to the list of dangers through which scallops at this age pass, and hence must play some part, probably very small in this case, in controlling the relative survival of the eggs that are spawned. Figure 7 is prepared from drawings of these protozoans made at the time of observation.

Behaviour of Trochophores under Laboratory Conditions. The eggs of the scallop, when shed, were extruded as a pink mass into the water surrounding the parent, this mass often containing so many eggs that the bottom of the tub and the parent, after the eggs had diffused into the water somewhat, could hardly be seen. These eggs invariably settled within five minutes upon the bottom. When first shed, their appearance was as in I of figure 8; but in a very short time they swelled up to their normal size, which was found last summer (1933) to be between 0.065 and 0.079 mm. diameter. The explanation of the great variety of shape in the freshly-shed eggs is, of course, that these eggs have been under some pressure within the ovary and have not had room to expand to their natural spherical shape.

The eggs remain lying upon the bottom, being considerably heavier than water, until in the course of their development they grow the cilia characteristic of the trochophore stage which enable them to swim. In the late gastrula stage, these cilia appear on the surface of the embryo; and under the microscope this stage can often be detected in the living state (it is somewhat difficult to discern characteristic structures as the larvae are quite opaque) by watching small particles near it. Many of these particules can be seen to move towards the larva, suddenly pass it and move away again, due to the current of water that is set up by the beating of the cilia in the embryo scallop's proximity.

Later, the apical tuft of cilia appears on the animal. This may be mistaken for a single flagellum but in reality it consists of several long cilia held closely together. It is used, however, much as a flagellum with a tractella beat, as the trochophore always swims with it in advance and it can be seen to be vibrating as the animal moves along.

At first, the motion of the young trochophore is somewhat slow, and in spirals, probably due at this time to the incomplete development of all the cilia. As time passes, however, the movement becomes more active, the spirals widen, and eventually the trochophores are to be seen swimming very actively in straight lines and at all depths in the jars. This would appear to show that they are quite capable of swimming up at this time into the current above a scallop bed, to be carried perhaps quite a long way before settling upon the bottom at the termination of the veliger stage.

Some rough experiments, directed mainly to see whether light had any considerable effect in determining the time of their swimming at all depths, were performed. Thus jars containing trochophores swimming at all depths were respectively exposed to light and kept in darkness for a period of about two hours, at the termination of which period they were examined with a hand-lens to determine whether the larvae were still swimming or had settled. No change at all was seen in the conditions in either jar. Again, into a dish was placed some water containing trochophores. Light conditions were so arranged that at one end of the dish there was bright light, whereas at the end opposite there was very subdued light. The trochophores apparently showed no preferences for either condition, remaining constantly quite eqully distributed throughout the length of the dish.

Whether the larvae at this stage are phototropir or not, it would be hard to say from this somewhat scanty data. It would seem that they are not under the conditions to which they were subjected. Yet an examination of plankton tows taken in the St. Croix river (1933) seems to indicate that the

planktonic veligers of the common mussel (Mytilus) tend to avoid the strong midday light at the surface by migrating downwards, like many other animals of the plankton; while in tows taken in L'Etang Harbour during early afternoon on August 24, 1934, at both the surface and at the bottom, the only scallop veligers that were found were taken in the bottom tows. Perhaps it is later in their development that the larvae begin to respond to the presence or absence and to the degree of light.

V. Lethal Temperatures

During the course of the summer these were determined for adult scallops (male and female), trochophores, and freshly-shed sperm. These temperatures, which have been determined for a great variety of animals at St. Andrews in the past, have been defined as the temperatures at which these animals have died, subsequent to a process of heating or cooling that has been controlled at the rate of 1°C. every five minutes. For any particular species, the lethal temperatures appear to come within very narrow and definite ranges, and various species have been compared with each other as to the position of these ranges. At most, the significance of a measurement such as this, which does not attempt to approximate the developmental extremes themselves, can only be comparative. However, there appears to be some correlation (Henderson, (4)) between the so-called lethal temperature and the relative depth in the sea at which the animal concerned lives. It is interesting to compare the high lethal temperatures of the adult scallop, its larval trochophore and its spermatozoa.

Adult Scallops. In all, thirty-three L'Etang scallops (19 males and 14 females) were used in a series of four experiments. In each experiment, the rate of increase of the temperature was kept at 1°C. in five minutes. At definite temperatures, certain numbers of the animals were taken out of the tub in which they were being heated in sea-water and were placed in water of the same temperature as the original temperature of each experiment, and were left there for twenty-four hours, when they were examined as to whether they had recovered or died. Table XXI summarized the results.

Table XXI. Lethal Temperatures of Adult Scallops

Temperature at which removed	Scallop	Result after 24 hours.
26.3	Male	Revived
27.3	"	"
28.2	"	"
28.6	"	"
28.6	Female	"
28.6	Male	"
29.3	"	Died after 48 hrs.
29.6	"	Died
29.6	"	Revived
29.6	"	"
29.7	Female	"
29.7	"	"
29.7	Male	"
30.3	"	Died
30.6	Female	Revived
30.6	Male	Died
30.6	Female	"
30.6	"	Revived
30.6	"	Died
30.7	Male	Revived
30.7	Female	"
30.7	"	Died
31.3	Male	"
31.6	Female	"
31.6	Male	"
31.7	Female	"
31.7	"	"
31.7	"	"
32.4	Male	"
32.6	Female	"
32.6	Male	"
33.1	"	"
34.2	"	"

It can be seen from this table that the lowest temperature at which death took place was 29.3°C., whereas the highest temperature from the effects of which a scallop managed to recover was 30.7°C. It is thus evident that the lethal point is different for different animals, and most probably may be taken as approximately 30.6°C., for the species as a whole. This is fairly low in comparison with those of some other forms, but compares favourably with those of forms such as Modiolaria discors (31.9°C) which are generally to be found in the same locality and at the same depth as Placopecten.

2. Trochophores. Some water from a jar in compartment B_4, containing a large number of apparently healthy and actively swimming trochophores, was placed in a glass finger-bowl, some fresh sea-water added, and the whole was heated at the rate of 1°C. every five minutes, upon the stage of a binocular microscope. It was thus possible to observe accurately and clearly all the movements of the larvae during the whole process. Table XXII summarizes the results, commencing at the 23.4°C. point.

Table XXII. Lethal temperatures of Placopecten trochophore larvae.

Temperature °C.	Condition of Trochophores
23.4	Actively swimming at all levels
24.3	"
25.3	"
26.4	"
27.3	"
28.3	Majority actively swimming at all levels
29.3	"
30.3	"
31.3	Motion more sluggish. Cilia slow
32.3	" " . Several settled to bottom and quiescent.
32.5	Motion practically stopped in all. Cilia beating only feebly.
32.9	Only one or two show slight rotary motion
33.4	No motion at all. All on bottom, quiescent
26.5	After cooling water (one hour). All embryos dead on bottom.
17.3	14½ hours later. " " " " "

It can be seen here that the lethal point was evidently between 32.3 C. and about 33 C., since between these two temperatures all the trochophores died. It is interesting to note that this figure differs from that obtained for the adult scallops by something like 2 C. This difference cannot be explained easily in the light of the data given; but its explanation very probably lies in the difference between the activity of metabolism, hence the relative resistance to external factors, of the adult and the larva. During the larval stages, growth is proceeding very rapidly and the rate of metabolism is relatively high, as in all animals; and it is probable that this added resistance to environmental factors and their effects, such as heat, is demonstrated visibly in the above experiment.

3. Spermatozoa. During a lethal temperature experiment that was being conducted upon some adult scallops on August 13, 1934, several male scallops threw large quantities of sperm into the water in the tub. The first was extruded when the temperature was 18.3°C. and the process continued at least up to 20.3°C., by which time the tub was so full of sperm that not a scallop could be seen in the water. The opportunity was taken of examining microscopically the water from time to time, and in this way the lethal point of the spermatozoa was determined concurrently with that of some adults. Table XXIII constitutes the results of these periodical examinations, beginning at a temperature of 25.3°C, up to which time the sperm had appeared very active.

Table XXIII. Lethal temperature of Placopecten Sperm.

Temperature °C	Condition of Spermatozoa
25.3	All active
26.3	"
27.3	Active. Some sluggish
28.2	" "
29.3	Much more sluggish. Some dead.
30.3	Practically all movement ceased.
31.3	All dead
32.4	"

The lethal point here is quite definitely between 29.3 and 30.3, which is slightly lower than that of the adult scallop, and considerably below that of the trochophores. The sole function of the spermatozoon is to find an egg and to fertilize it; and after that, its function being complete, it exists no more as an individual. Allowance is made for the chances of sperm not finding the eggs in the vast numbers that are produced; and partly because of this, but possibly also because the rate of metabolism in a spermatozoon is very low, there is probably little need for a highly developed resistance to environmental conditons. This may or may not explain the relatively low lethal point determined about; it cannot, however, be taken as a conclusion.

VI. Summary

Examination of the rings upon further shell samples to determine the growth rate in different localities, namely, The Wolves, in the bay of Fundy, and L'Etete Passage, N.B., showed that scallops in the latter place, living in a strong current which probably supplies them with plenty of food, show the more rapid rate of growth, attaining the legal size of

4 inches with between three and four rings; whereas scallops from The Wolves at the same size possessed 4¼ or 4½ rings, in this respect agreeing very closely with scallops from Digby and Grand Manan.

Verification of the validity of the rings as a criterion of annual growth is being undertaken. This has yet to be completed. Scallops have been planted in the St. Croix river for the purpose of following actually the growth of their shells during the winter, and for the determination of the time of deposition of the rings.

A comprehensive series of experiments with fertilized scallop ova was conducted to determine the rate of development of the larvae under laboratory conditions. Eggs were reared at eight temperatures ranging from 2.16 to 17.42°C. From 5.26°C. to 17.42°C., development took place at rates varying with the temperature, the healthiest development taking place at 10.32°C., which approximates the normal temperature of the sea during the summer months. Development never proceeded beyond the trochophore stage, although conditions of light, salinity and oxygen were eliminated as a cause of this; leaving, thus, lack of suitable food material as the only remaining probable cause.

Larvae were reared from fertilized eggs under laboratory conditions at seven salinities ranging from 30 o/oo to 5 o/oo over temperature ranges of 5°C., 9°C., 12°C., and 14°C. Developmental rate increased with increase in temperature up to the trochophore stage. The larvae developed in salinities of 25 - 30 o/oo, but a retarding effect was observed at 25 o/oo. Below 25 o/oo no development of any significance took place.

Lethal temperatures were determined for 33 adult scallops, consisting of 19 males and 14 females, to be approximately 30°C.; for freshly-shed spermatozoa, approximately the same; and for trochophore larvae, 32.3 - 33.4°C.

Two apparent parasites (Ciliate protozoans) were observed upon scallop eggs during the experiments, and described.

VII. Problems Suggested in the Course of the Work

Absolute verification of the validity of the rings as a criterion of annual growth. This should be done soon, since much of the problem of growth is based upon the assumption that these rings are annually deposited. It is essential not only to follow the experimental method already begun right through but it is also essential to use the statistical method, using regular samples from one place throughout at least one whole year.

At what stage in their life-history do the scallops suffer the greatest mortality at the hands of their environment? This involves a comparison between the number of youngest larvae and the number of oldest larvae in the plankton, and of the oldest planktonic larvae with the youngest spat. It also involves a careful study of the populations of adult scallops upon selected beds over an extended period of time, with a view to following the survival of particular age-groups.

What are the causes of such mortality, if any exist? This involves correlation and subsequent checking by experimentation, of mortality with various environmental factors. This phase would probably demand much time and results might not be forthcoming quickly.

The spawning of adult scallops. In spite of the fact that a fishery for these animals has existed for a considerable number of years in Eastern Canadian inshore waters, practically nothing appears to be known about the actual spawning activities of the animals. The time at which spawning begins and again ceases for the season; the conditions that promote or control the act of spawning; the amount of spawn liberated; and how many times a year a single scallop will spawn, have all not been explained. A study of this phase would involve a careful periodical examination of large numbers of scallops, and hence would have to be conducted in a locality where they are easily obtainable in large quantities, such as Digby. Here scallops exist in large quantities apparently, even in the Gut and Annapolis Basin.

When do scallops mature? We can find no literature to show that the exact age at which Placopecten matures and first spawns is known.

The growth of larvae under natural conditions. It is necessary in this phase to take a large number of regular plankton hauls where scallop larvae are known to be abundant, throughout one complete summer spawning season. The results of quantitative estimation of the larvae in the water could be correlated very probably with those from (4) above.

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IX. Appendix

The course of the experiments that were undertaken during the summer upon the growth of the larvae embraced a considerable number of phases that in a discussion such as that already accomplished in the present report could in many ways be considered superfluous. However, the results of such experiments as were not incorporated earlier into this report are included here in an appendix.

Table XXIVI Salinity - 30 o/oo. Mean Temp. 12.34°C. Max. Temp. - 12.6°C. Min. Temp. 12.0°C.

B_2/

Aug.	6	6	7	8	9	10	11
Hours' Duration	0	5½	9	40	59	82	106
Stages 1	100	67	50	21	9	2	
2		33	21	24	13	6	
3				16	10	4	
4				2	12	1	
5							
A		3	13		3	1	
B					2	44	47

Table XXV. Salinity - 30 o/oo. Mean Temp. 14.37 C.
Max. Temp. 14.7 C., Min. Temp. 13.6 C.

C_1

	Aug. 6	6	7	8	9	10	11	12
Hours' Duration	0	5½	9	42	63	86	107	129
Stages 1	100	67	41	5	3			
2		33	20	28	8			
3				27	13			
4				20	24	3	1	
5								
A		3	7	2	3			
B				1	4	60	50	62

Table XXVI. Salinity - 30 o/oo. Mean Temp. 17.42 C.
Max. Temp. 17;8 C. Min. Temp. 16.9 C.

D_1

	Aug. 6	6	7	8	9	10	11
Hours' Duration	0	5½	9	43	63	86	107
Stages 1	100	67	44	8			
2		33	6	1	1		
3				15	2		
4				14	10	3	
5							
A		3	20		1		
B					12	49	44

Table XXVII. Salinity - 27.5 o/oo. Mean. Temp. 5.06 C.
Max. Temp. 6 C. Min. Temp. 4.4.C.

A_{11}

	Aug. 17	17	18	19	20	21	22	23	24	25
Hours' Duration	0	4	16	40	64	88	112	136	157	184
Stages 1	100	100	70	42	39	62	22	12	8	
2		1	1	9	14	16	20	17	12	
3							7	8	18	
4							2		10	
5										
A					2	2	2	3	12	
B					2	1	8	4	12	20

Table XXVIII. Salinity 27.5 o/oo. Mean Temp. 12.42 C.
Max. Temp. 12.5 C. Min. Temp. 12.3 C.

A_{13}

	Aug. 17	17	18	19	20	21
Hours' Duration	0	4	17	41	65	89
Stages 1	100	100	38	13	1	
2		1	32	13	2	
3				10	4	
4				5	15	
5						
A			5	5		
B				2		20

Table XXIX. Salinity 27.5 o/oo. Mean Temp. 14.20 C.
Max. Temp. 14.5 C. Min. Temp. 13.7 C.

A_{14}

	Aug. 17	17	18	19	20	21
Hours' Duration	0	4	17	41	65	89
Stages 1	100	100	18	3		
2		1	13	6		
3				11		
4				9	19	
5						
A			1	1		
B				4	11	33

Table XXX. Salinity 20 o/oo. Mean Temp. 5.21 C.
Max. Temp. 5.7 C. Min. Temp. 4.9 C.

A_2^2

	Aug. 6	6	7	8	9	10	11	12	13	14
Hours' Duration	0	5½	13	33	57	81	104	128	152	176
Stages 1	100	67	76	59	25	28	58	51	18	
2		33	15	29	14	19	13	7		
3										
4										
5										
A		3	4	2	12	2	8	12		
B						4	4		52	56

Table XXXI.

Salinity 20 o/oo. Mean Temp. 12.34 C.
Max. Temp. 12.6 C. Min. Temp. 12.0 C.

$B_2 2$

Aug.	6	6	7	8	9	10	11
Hours' Duration	0	5½	14	36	62	82	107
Stages 1	100	67	24	38	16	2	
2		33	10	4	3	2	
3					1	1	
4							
5							
A		3	28	6	6		
B			2		2	49	63

Table XXXII. Salinity 20 o/oo. Mean Temp. 14.27 C.
Max. Temp. 14.6 C. Min. Temp. 13.6 C.

$C_1 2$

Aug.	6	6	7	8	9	10
Hours' Duration	0	5½	21	42	62	86
Stages 1	100	67	27	20		
2		33	4	8		
3						
4						
5						
A		3	19	4	8	
B				1	2	26

Table XXXIII. Salinity 15 o/oo Mean Temp. 5.26 C.
Max. Temp. 5.5 C. Min. 5.0 C.

$A_2 3$

Aug.	6	6	7	8	9	10	11	12	13	14
Hours' Duration	0	5½	13	34	57	81	105	128	153	176
Stages 1	100	67	62	86	51	45	71	19	47	
2		33	14	27	12	14	17	6	12	
3										
4										
5										
A		3				2		5	29	
B				2		3	6	3	14	42

Table XXXIV. Salinity 15 o/oo. Mean Temp. 12.34 C.
Max. Temp. 12.6 C. Min.Temp. 12.0 C.

$B_2 3$

	Aug. 6	6	7	8	9	10	11
Hours' Duration	0	5½	14	40	62	86	107
Stages 1	100	67	37	39	35	4	
2		33	7	2	3	1	
3							
4							
5							
A		3	3		7		
B			1		2	47	61

Table XXXV. Salinity 15 o/oo. Mean Temp. 14.27 C.
Max. Temp. 14.6 C. Min. Temp. 13.6 C.

$C_1 3$

	Aug. 6	6	7	8	9	10
Hours' Duration	0	5½	14	42	63	86
Stages 1	100	67	43	32	19	
2		33	7			
3						
4						
5						
A		3	3	2	5	
B			14	1	1	37

Table XXXVI. Salinity 10 o/oo. Mean Temp. 5.26 C.
Max. Temp. 5.5 C. Min. Temp. 5.0 C.

$A_2 4$

	Aug. 6	6	7	8	9	10	11	12	13	14
Hours' Duration	0	5½	13	34	57	81	104	128	153	176
Stages 1	100	67	64	48	21	53	43	36	27	
2		33	29	29	7	24	13	10	7	
3										
4										
5										
A		3		1		6	14	9	8	
B					1	1	10	25	34	34

Table XXXVII. Salinity 10 o/oo. Mean Temp. 12.34 C.
Max. Temp. 12.6 C. Min. Temp. 12.0 C.

$B_2{}^4$

	Aug. 6	6	7	8	9	10	11
Hours' Duration	0	5½	14	41	62	82	107
Stages 1	100	67	41	52	29	15	
2		33	15	2		2	
3							
4							
5							
A		3	2		5	7	
B					1	39	36

Table XXXVIII. Salinity 10 o/oo. Mean Temp. 14.27 C.
Max. Temp. 14.6 C. Min. Temp. 13.6 C.

$C_1{}^4$

	Aug. 6	6	7	8	9	10
Hours' Duration	0	5½	21	42	63	86
Stages 1	100	67	43	29	3	
2		33	19	3	2	
3						
4						
5						
A		3	1	1	4	
B					9	55

Table XXXIX. Salinity 5 o/oo. Mean Temp. 5.26 C.
Max. Temp. 5.5 C. Min.Temp. 5.0 C.

$A_2{}^5$

	Aug. 6	6	7	8	9	10	11	12
Hours' Duration	0	5½	13	34	57	81	105	128
Stages 1	100	67	58	29	21	21	21	
2		33	24	9	3	3		
3								
4								
5								
A		3		1	4			
B				4	9	53	43	58

Table XL. Salinity 5 o/oo. Mean Temp. 12.45 C.
Max. Temp. 12.6 C. Min. Temp. 12.3 C.

$B_2 5$

	Aug. 6	6	7	8
Hours' Duration	0	5½	13½	35
Stages 1	100	67	9	
2		33	5	
3				
4				
5				
A		3		
B			39	60

Table XLI. Salinity 5 o/oo. Mean Temp. 14.0 C.
Max. Temp. 14.4 C. Min.Temp. 13.6 C.

$C_1 5$

	Aug. 6	6	7	8
Hours' Duration	0	5½	14	42
Stages 1	100	67	47	
2		33	19	
3				
4				
5				
A		3		
B			9	60