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The Canadian Scallop. Its Fishery, Life-History and some Environmental Relationships.

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THE CANADIAN SCALLOP

Its Fishery, Life-History and some Environmental Relationships

by

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By

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PART I.

THE FUNDY SCALLOP-FISHERY

GENERAL INTRODUCTION

The present report is comprised of three parts, corresponding each to a separate phase of the investigation into the fishery and the general life-history of the scallop. These parts are as follows:

I. The Fundy Scallop-Fishery

II. The Growth of Adult Scallops

III. The Development of Scallop-Larvae with relation to Environmental factors

The actual investigations were conducted under the guidance of Dr. A.G.Huntsman, Director (now Consulting Director) of the Atlantic Biological Station at St. Andrews, New Brunswick. The work was mostly undertaken at the Station during the summers of 1931-35, under the auspices of the Biological Board of Canada. Its purpose was to supply some information, of use to the fishery, upon the scallops, which hitherto appear not to have received much attention in this regard.

PART I. THE FUNDY SCALLOP-FISHERY

The bulk of the material forming the basis for this study of the conditions under which the fishery exists on the eastern coast of Canada was obtained during the summer of 1931, at which time a survey was conducted by the Biological Board of the fishery industries of the Fundy Area. This has, however, been added to considerably in subsequent years, particularly the present (1935).

1. THE SCALLOP'S NAME

Placopecten grandis Solander has been referred to in various text-books as Pecten tenuicostatus Mighels, a name employed by Drew (1) in his monograph on the species; Pecten magellanicus Gmelin; and Pecten grandis (Solander). Besides this species, there is one other that is at all abundant in the Fundy Area. This is Pecten islandicus, a smaller form; and since it has no commercial value, it does not concern us here. The two species are shown side by side in Figure 1.

Placopecten occurs in the Bay of Fundy in sufficient quantities, and is of sufficient size, to support a thriving fishery. In the Fundy region the species is referred to as "Scallop" or "Scollop," in contradistinction to P. islandicus, which is erroneously termed the "Cape-Cod Scallop." The true Cape-Cod, or "Bay" Scallop, is Pecten irradians Lamarck, a form occurring in inshore waters very abundantly from Cape Cod southwards, and very seldom straying as far north as

Fundy waters. In the American markets, Placopecten is referred to as "Sea-scallop" or "Giant Scallop", the former name alluding to its habitat, which is in deeper water than that of the Bay Scallop; and the latter to its considerably greater size. Other names by which the species is called are "Great Scallop," "Smooth Scallop" (from its peculiarly smooth shell), and "Escallop." Young scallops are generally called "Button Scallop" or "Seed Scallops"; and when younger yet, just after they settle on the bottom at the termination of the free-swimming larval period of their lives, they are, like oysters, termed "Spat".

2. DESCRIPTION

The Giant Scallop is one of the largest species. A specimen from Campobello Island, New Brunswick, possessed the following dimensions:

Length (Umbo to opposite edge of shell) 6.8 inches

Width (from side to side) . . . . 7.8 inches

Depth (greatest distance between shells when closed) 2.5 inches.

This would be considered a large specimen, and would yield several ounces of "meat". Smith (2) states that, on the Maine coast, scallops attain a diameter of nine inches, and that the edible muscular portion of a scallop of this size is about three inches in diameter and weighs nine or ten ounces. The average size of the "meat", however, in the Fundy region, is a little more than one inch in diameter, and I have never seen a specimen, in the many thousands that have come to my notice from the whole eastern coast of Canada, anywhere approaching the size of the example quoted by Smith.

The "meat" or "eye" of the scallop, which is the only part of it eaten in the Fundy area, consists of the adductor muscle which, in the living animal, is used to draw the two valves of the shell, to each of which it is attached, together. When the animal is suddenly excited it generally closes its shells together with a snap. This is effected by the sudden contraction of the adductor muscle. The meat varies much in quality from place to place and according to the age of the scallop. Young scallops generally possess white, firm meats; and if the conditions for growth are exceptionally good, as in the Annapolis Basin, this meat may grow to be very large in proportion to the shell, and may take on a very delicate pinkish tint. Occasionally meats are found that are actually salmon-red. The actual reason for this colourization is not clear. Old scallops that have passed their prime (eleven years and upwards) are usually characterized by small, shreddy meats, coloured yellow or grey ("nigger-scallops"); and such meats are generally rejected as unmarketable by the fishermen. They are not attached firmly to the shell, and often the process of shocking tears the meat of an old scallop away from the shell. Figure 4 shows two scallops, one young and the other old, and indicates the typical difference in the meats.

The shell of the scallop is composed of two valves, both rounded in outline; but the right valve, on which the animal habitually lies when alive, is much flatter than the left, and is generally white. The left valve, which is pronouncedly convex, is coloured on the outer surface, the colour varying greatly, ranging from dark red-browns, through yellows to whites. A violet tinge is quite frequent.

Both valves are covered with very fine grooves which are found to be in two series -- those radiating from the umbo or "beak", and those concentric around it. The latter grooves, or "check-marks", are laid down at intervals in the growth of the animal and will be discussed in detail later in this report. Very often, especially in young specimens, the colour pattern of the Giant Scallop is found to coincide with the arrangement of the grooves. Thus scallops with radiating bands or concentric rings of darker colour on a light background are comparatively common (See Figure 1). As the animals grow older, however, the colour pattern loses much of its beauty.

The shells of scallops, particularly old ones, are very often attacked by the yellowish sponge, Cliona sulphurea, which is able by enzyme action to bore holes in them. Some shells are riddled by these holes and when the sponge eventually dies, the holes are very often occupied by many of the tube-dwelling worms, particularly Dodecaceria. It is only very seldom, however, that the sponge is able to penetrate through to the inner side of the shell, for as fast as it bores, the scallop strives to cover it up by the deposition of nacre on this inner surface. Consequently some old shells that have been badly attacked by Cliona are found to be very thick and massive (Figure 3).

The living part of scallops is often quite highly coloured (mantle lip red-brown, yellow or jet black; ovary red; stomach gland greenish-brown), and possibly due to this, people are prejudiced against eating the mantle, visceral sac and other parts considered as "waste"; hence only the muscle, because of its firm texture and pure white appearance, is eaten. Figure 2 shows the general appearance of a scallop with the right valve, mantle and gills removed, showing the viscera and in the centre the powerful adductor muscle.

5. ECONOMIC VALUE

The economic value of the Fundy Scallop-Fishery to Canada can easily be seen when it is considered from these standpoints: (a) the high percentage it forms of the total Canadian scallop catch (71.4 per cent), (b) the high prices generally obtained, (c) the number of men and boats employed in the fishery and (d) the food value of the scallop meat itself.

An idea of the importance of the scallop-fishery to the Fundy area may be gained by glancing at Table I, which shows the catch (in barrels), the value, and the yearly percentage of the total Canadian Atlantic coast scallop catch produced by the Fundy area, as obtained from the Fisheries Statistics of Canada for the years 1920-1929.

YEAR	BAY OF FUNDY CATCH (in Barrels)	YEARLY VALUE OF CATCH (in Dollars)	BAY OF FUNDY CATCH AS % OF YEARLY CATCH ON CANADIAN ATLANTIC COAST
1920	106	499	2.5
1921	2,207	12,460	45.9
1922	7,296	33,761	68.2
1923	9,432	54,804	60.7
1924	5,191	32,721	50.2
1925	12,295	62,599	69.5
1926	15,170	104,405	65.4
1927	32,617	176,296	80.5
1928	21,968	121,036	84.2
1929	13,529	84,195	75.5
1930	14,488	69,929	77.7
1931	8,509	26,655	71.5
1932	17,630	55,751	75.3
1933	39,494	149,623	91.4
AVERAGE	14,281	70,340	65.6

Highest percentage of any one commercial fish in the Fundy area for 1928.

TABLE I. Yearly catch of scallops in the Fundy area for the years 1920-33, with values, and per cent of total Canadian Atlantic Coast catch.
(From the Dominion Fisheries Statistics)

When it is realized that on the average for these years, 65.6 per cent of the total Canadian Atlantic Coast scallop catch was taken in the Fundy area, and that in 1933 this percentage reached 91.4, it will at once be seen what a rich field in this particular branch of industry is provided by this region, and how the region has what is virtually a monopoly of the Canadian scallop trade. It can be seen how the rest of the Dominion almost depends upon the Fundy area for its scallop supply. Due to the present mode of distribution of the catch, most of the scallops are shipped to the American markets; but it can be seen how, were the Canadian inland markets exploited to the fullest extent, the result of a cessation of the fishery for a while would be felt very keenly over a large area by the consumers.

The price obtained for fresh scallops in the past has fluctuated considerably. In 1920, when the Digby fishery, which is now the most extensive, began, from five to six dollars were regularly obtained by the fishermen for a gallon of meats. Increasing competition, both in Digby itself and in the foreign markets, has reduced this price since that time until, at the present time, the Fundy scalloper considers himself fortunate if he can obtain $2.50 per gallon; and during the summer months, when spawning renders the scallops poor in quality, this price is still further reduced to $1.00 or even to 75 cents per gallon. A fair average price for winter scallops at the present time would be about $1.75 a gallon. Even so, the profits in scalloping are fairly high, as can be seen from a glance at Table II, which summarizes the average expenses and receipts of a Digby scallop-boat for one day's dragging. It must be remembered, however, that the initial cost of a scalloping outfit is high; and that not all fishermen can afford it. Also, scalloping can be done to best advantage only in comparatively calm weather; and since the open season is during the winter time, it is often impossible for the men to drag on account of the heavy weather encountered in the Bay of Fundy. Indeed, at Digby, very often the fishermen cannot go out for ten days or a fortnight at a stretch. It is thus seen that the profits of the scalloper depend largely upon the weather. In good weather, and with a good market, scalloping is one of the most profitable of all fisheries, although of recent years the market price has tended to fall somewhat greatly. Some of the larger boats are equipped with Diesel engines, and the cost of fuel oil is consequently much lower than gasoline for their owners. Such boats can go further afield. The considerable expense, too, of shocking the catch is mitigated entirely by some of the crews, who shock their scallops immediately they are caught, returning the empty shells to the beds.

	ITEMS	DOLLARS
1.	Gasoline for boat, 25 gallons @ 23 cents a gallon	4.25
2.	Oil	1.10
3.	Empty barrels for shipping	3.00
4.	3rd and 4th men of crew, on wages	6.00
5.	Trucking	.50
6.	Upkeep per trip (repairs)	2.50
7.	Commission, express and freight to Boston market	19.11
8.	Boat's share (depreciation)	23.62
	TOTAL COST for one day	60.08
	Received for 54 gallons (average day's catch) @ 1.75	94.50
	Cost	60.08
	PROFIT	34.42

TABLE II. Expense Account of one day's scalloping off Digby, N.S. -- gasoline boat with crew of four.

(Modified from J. J. Wallis, "Canadian Fisherman," Oct. 1928)

The scallop fishery of Digby and Annapolis Counties, Nova Scotia, provides work to be done each winter for from 25 to 90 boats, varying in size from small, open motor-boats up to specially designed scallop-draggers, about forty feet in length, every boat being supplied with scallop-gear and manned by from two to four men. In 1926, according to the Canadian Fisheries Statistics, 90 sets of scallop-drags were in operation from Digby county alone. With the growth of the fishery and the accumulation of profits by the fishermen, the older, small open boats have now been largely replaced by highly efficient scallop-draggers, each equipped with elaborate gear and capable of hauling up to six drags together.

Apart from those who actually do the fishing, there is a large number of workers ashore attending to some of the shocking, to the packing and the shipment of the scallops after they are landed. The local blacksmith in Digby has a very extensive trade manufacturing scallop drags, bridles and bars. The fishery, therefore, is of great importance to the fishermen of the Bay of Fundy as a whole; and forms the chief industry of the town of Digby during the wintertime.

In spite of the fact that scallops are considered more as a luxury than as a food, their food value is very high, according to Atwater and Bryant's (3) results in the chemical analysis of the muscle of the Bay scallop (Pecten irradians). These results are summarized briefly in Table III.

	WATER %	PROTEIN % N x 6.3	FAT %	TOTAL % OF CARBOHYDRATES	ASH %	FUEL VALUE CALORIES PER LB.
Minimum	77.8	14.5	--	1.1	1.3	305
Maximum	82.8	15.1	0.3	5.6	1.5	385
AVERAGE	80.3	14.8	0.1	3.4	1.4	345

TABLE III. Chemical Composition of Scallop Adductor Muscle.

(After Atwater and Bryant)

From this it will be seen that the protein value is high--higher, according to Tressler (4), than in any of the other common edible shell fish. Fat content is very low. It must be remembered that these figures apply only to the adductor muscles of the scallops, whereas in other shell fish, such as the oyster, of which all but the shell may be eaten, they would apply to the rest of the flesh as well.

Scalloping is in many places a stand-by for the fishermen when fishing of other types is not worth-while. In Grand Manan, for instance, the herring fishery takes up all the fishermen's attention during the summer-time; but in the winter, when the herring have gone, many of the weir-tenders are fitted out with scalloping gear, and the fishermen take to scalloping until the herring arrive again during the following year.

There is as yet no American duty upon fresh scallops entering the United States for market. Since the chief markets for sea-scallops are in the United States (Boston, New York, etc.), this tends to make shipment from the Canadian centres all the more profitable for those concerned in the business. This spring (1935), however, there has been some agitation in the State of Massachusetts for a tax to be levied upon foreign scallops entering the United States. The tax, as suggested by

Mr. Gifford to Congress, would be at the rate of seven cents on the pound. Needless to say, if this tax is placed upon Canadian scallops, the industry will be seriously crippled for a time; at least until the home markets can be canvassed sufficiently to remedy the trouble. However, as yet, there is no tax upon Canadian scallops entering the United States.

4. METHODS OF CAPTURE

For the taking of scallops in sufficient quantities for market, the requirements are: a boat with sufficient power to drag the scallop-drags along the bottom of the sea; a hoisting winch and engine; a towing-warp; and a crew capable of handling the foregoing gear to the best advantage.

Throughout the course of the scallop fishery in the Fundy area, particularly since the Digby fishery began in 1920, continual changes and improvements have taken place in the gear used. In earlier times, rowing-boats and single drags, of varied designs, and hauled by hand, were used. With the introduction of gasoline and Diesel engines, the boats were powered by these, and were made larger in size. Hoisting winches were rigged up on deck to bring the heavily laden drags up from the bottom of the sea. For a long time, only single drags were used, but eventually teams were introduced.

At Digby, the first teams consisted of two four-foot drags affixed one at either end of the "spreader" or "whiffle-tree", an iron bar which is held at right angles to the towing warp to which it is affixed by two or more chain bridles and a swivel. A year or two later, teams consisting of three drags, each 3½ feet across, were introduced at Digby.

The four-foot drags used in pairs were somewhat unwieldy and not so effective as the smaller ones that now replaced them in most of the better equipped boats. A further innovation was the introduction of an extra 3½-foot drag behind the middle drag. This extra drag became known as a "trailer"; but was not very satisfactory due to its unwieldiness when the team was being hoisted aboard (See Figure 6).

Still more recently yet smaller types of drags have been introduced. The first was three feet across. These are hauled along the bottom of the sea in teams of three, four, and even five. Captain Amos Brannen of Yarmouth was one of the first to adopt this gear. At the present time, the standard Digby scallop drag is only about 2 feet 8 inches across the mouth; and in the larger boats, such as that of Captain Shirley Tidd, six of these small drags are attached to one spreader. The latter has, of course, greatly increased in length to accommodate the increasing number of drags that are attached to it.

The types of boats used at the present time in the scallop-fishery vary greatly, not only from place to place, but also in one locality itself. Many boats, from the largest weir-tenders down to the small open boats are used for scalloping at Grand Manan, where most of the dragging is done in comparatively shallow water. In Digby, however, the fishery has of recent years assumed such large proportions that a special type of boat has been designed for the work; and boats of this type are in general use there. Some of these boats are figured (Figure 5). They are generally from thirty-five to forty feet in length, with marine engines of from 10-30 horsepower. A boat such as this would cost the fisherman about three thousand dollars.

From the base of the mast, a boom projects over the gunwale of the boat. This serves a double purpose; it holds the drags clear of the boat, and it takes the strain when the drags catch in the rocks on the sea-bed. The towing-warp passes from the "hoist", or winch, through a pulley block at the end of this boom, down to the drags at the bottom. In action, the boom must be kept horizontally over the side so that if the rocks pull the boat up short while dragging, the latter will tend to swing round, and much of the strain will be alleviated. If the boom be kept nearly vertical, the tendency will be for the boat to be pulled downwards, and a great strain will be set up, with the possible resultant parting of the warp and loss of the gear.

The hoisting engine is situated on the deck of the boat, generally on the port side just forward of the wheelhouse and beside the hold. It is generally run by gasoline and develops from three to six horse-power. In some of the boats, however, among them Captain Shirley Tidd's "Jessie May", the hoist is connected directly by a chain drive with the marine engine below decks.

The arrangement of the gear when a boat is scalloping is figured (Figure 6), together with the arrangement of the drags in different types of teams.

The drags themselves have varied much in shape in the past. Some of the older types shown (Figure 7) are used in various localities in the Fundy area, particularly Campobello Island and Grand Manan. Some have only one scraper, hence can only operate when they fall on the correct side. The more modern types, however, possess a scraper on both sides, so that whichever way they fall on the sea bottom, they will operate equally efficiently. The scallop-drag, or "scallop-rake" as it is sometimes called, is composed of two chief parts, the bag and the frame. The bag is of the same width throughout, and in the more modern types is composed entirely of wire rings joined together by smaller rings or "washers". In the Digby drags, these rings are generally about ten deep on the bag. They have to be replaced from two to four times a winter, depending upon the wear and tear and also upon who manufactured them, since they vary considerably in quality. The best ("Acadia") rings come from a firm in Halifax and cost 3 cents apiece. Wire rings are found to stand much more wear and tear than rope, of which, however, the bags of some of the cheaper drags are made. By law, the larger wire rings used in the construction of the bag are not to be less than three inches in diameter. This is to allow free exit to such under-sized scallops as may enter the drag; although it is extremely doubtful if this method is at all efficacious in a drag on the sea-bottom, filled with large scallops that tend to block up the holes in the netting. This may be compensated for, however, by the fact that, in most drags, the wire-rings soon become very much distorted by the rough work, and often allow scallops of a size larger than four inches (the legal size) to pass through.

In order that the bag may be held open to the fullest extent, a wooden plank is fastened along the end of the net. To the centre of this is attached a short rope with a loop, which is used for tipping the contents out of the drag when it comes up on deck.

The frame of a scallop-drag is made of iron, and is rectangular in shape. The two longer sides, which may be 2 2/3, 3, 3½ or even 4 feet long each, are made in such a way that when the drag is hauled along the bottom of the sea, they will dig up any scallops that are encountered, which will pass between them into the bag. These sides are the scrapers, and are generally eight inches apart. They have to be renewed about twice a year, due to the heavy wear from constantly scraping the bottom of the sea.

In front of this rectangular frame there is an iron bar, which is of the same length as the scrapers, and which is fastened to the frame at either end and in the middle by stout iron stays. To the outer ends of these stays, in turn, are fastened three iron rods, capable of being moved up and down, and meeting at a point ahead of the drag. At this point a swivel is attached to allow the drag free swing.

A drag such as this costs about eleven dollars. The spreader, to which the team of drags is attached in a row, may be from eight to fourteen feet in length according to the number and size of the drags employed. To this spreader, two, three, or in the largest teams, five chain bridles are fastened at equal distances, and these meet at a point, where another swivel is attached. Hence in a team of six drags on a spreader, there will be seven swivels in all. The towing-warp is fastened to the spreader-swivel, and leads up to the boat. With a team of drags like this, many more scallops can be taken than if only one drag were used.

In such teams, the larger sizes of drags are sometimes used if it is intended to scallop on smooth ground. If the sea-bottom is not level, however, the smaller drags are found to be more effective because they can follow small depressions much better.

The weight of a set of drags may be seven or eight hundred pounds, including the spreader--fifteen hundred when full. It is to pull such a heavy weight along the bottom that the better equipped boats have such powerful engines.

In practice, the whole set of drags is lifted bodily in the air by the winch, so that it hangs from the end of the boom above the deck. Then, with the next roll of the boat, they are allowed to fall over the side into the sea, and sink rapidly to the bottom. A little more warp is allowed to run out (about half as much again as the depth of the water) to ensure proper scraping of the sea-bottom and to eliminate "jumping", and then the brakes of the hoist are applied to stop it. The warp is shifted to the horizontal dragging boom, the boat's engine started up, and the dragging takes place, the boat keeping ahead very slowly (3 knots, ca.). If the boat is not a very powerful one, some assistance is obtained by travelling with the tidal current; but many of the captains of the larger boats believe that more scallops are to be caught by dragging up-current. Slack tides are best in this respect. After from five to fifteen minutes, depending chiefly upon the abundance of scallops, the hoist is started up, the drags hoisted on deck, and the contents tipped out. In order that no time may be lost, the drags are immediately sent to the bottom again, and while another dragging is taking place, the men are busy shocking the previous catch.

The total number of scallops taken at every haul of the drags varies, of course, with a number of factors. At Digby, it is generally considered by the fishermen, however, that scalloping is not profitable unless 180 to 200 scallops or more come up at every haul. Sometimes the catch greatly exceeds this if the drags have happened to strike a very rich bed of the molluscs; and four to six hundred scallops may be taken at a haul. Occasionally the drags come up so full with scallops and practically nothing else, that they will sit upright on deck and have to be pushed over.

Another point should be mentioned here. It was stated by several fishermen who had done scalloping off Digby that much better results were to be obtained at night on scallop-beds than in daytime on the same beds. This has led many of the fishermen to the belief that in the daytime scallops can see a drag approaching, and that they avoid it by a rapid snapping together of the valves of the shell. Scallops are certainly able to swim with quite unusual ability for molluscs, but it is doubtful whether this would be the sole cause of the difference between day and night catches. It seems that in the daytime the sea is not generally so calm as it is at night; hence more jumping is liable to take place on the part of the drags in the daytime and less scallops will consequently be caught. That scallops can be very active, however, is amply borne out by an experiment conducted by a fisherman some years ago on one of the shallow-water scallop-beds off Grand Manan Island. He obtained a diving suit and went down to the bed with a basket, intending to catch some of the scallops. But as fast as he placed them in the basket, they jumped out of it. There may, therefore, be some substance in the idea of scallops of their own volition avoiding approaching drags during the daytime.

Dragging is the only recognized means of obtaining scallops in quantities in the Fundy area. Apart from this, however, many are often taken on trawl-lines. The line, lying on the bottom of the sea, slips accidentally between the open valves of the mollusc, which immediately snaps tight, and remains thus fastened to the line until it is taken off by the fisherman who hauls up the trawl. Off Digby, sometimes the fishermen obtain as much as a bucketful of scallops in this way at one setting of the trawl when it has been lying upon a scallop-bed. It was in this way that many of the best beds were discovered, including those in the Annapolis Basin, off Centreville, and the Lurcher Shoal.

It was thought that predatory animals might be likely to form a menace at times to the productivity of the scallop-beds. Such fish as cod, haddock and catfish (Anarhicas), and other animals such as whelks and starfish could very well feed on scallops; and if present in large numbers, might even prove dangerous to the existence of a bed. Upon being questioned, several scallop fishermen, both at Digby and Grand Manan, said that codfish and haddock were quite frequently to be found with young scallops in their stomachs. Some of the larger cod, too, had big scars all over their snouts, which the fishermen believed to be caused by scallops closing their shells on them and scratching them. It was thought that the codfish went "rooting" in the scallop-beds for young scallops and that in doing so, they received these scars. Whelks and starfish appear never to have been the cause of any trouble on the Fundy scallop-beds by reason of their virtual absence due to a difference in the bathymetric ranges of Placopecten and Asterias. One starfish, however, Hippasteria phrygeana, is in places very abundant.

At this point might be mentioned a singular case of commensalism that occurs very frequently between the giant scallop and three species of fish. A small fish, Neoliparis atlanticus J. and E., very often takes refuge between the valves of the scallops and is brought up quite frequently inside the latter in the drags. It appears that this habit is characteristic only of the younger stages of the fish. Observations on many hundreds of scallops seem to indicate that the fish first appear inside the scallops about the end of July; and they persist into the winter. They do not generally occur in great numbers, not over five or ten per cent of the scallops being inhabited.

Of similar habit, but far more plentiful, are the young of two species of hake, Urophycis tenius Mitchill, and U. chuss Walbaum. These fish begin to appear in the scallops about the middle of November, when they are not more than about an inch and a half long; and they persist in their habit right through the winter until the end of July, by which time most of them have grown too large to be contained within the scallops. During the winter, these young hake are so plentiful inside the scallops that the decks of the scallop-boats during shocking operations are "a mess of them"; and it is probable that more hake are killed in this way each year than are caught on trawl-lines, off Digby. As many as five young hake may be found within one scallop, although one or two is a more usual number. U. tenuis is by far the most common; and indeed, we have not yet seen an example of U.chuss from a scallop. That they do likewise is, however, testified amply by Welsh ("Copeia", No. 18. May 15, 1915, pp. 2-3), who found them to be very abundant in scallops from the New England coast.

None of these fish apparently do any harm to the scallops; and it is probable that they use the latter simply as a place of refuge during a somewhat critical period of their lives. (Figure 8).

5. DISTRIBUTION

The giant scallop (Placopecten grandis Solander) is found on the Eastern coast of North America from Capt Hatteras to Labrador. It has been taken at all depths ranging from low-tide-mark to a hundred and fifty fathoms of water, but is most abundant in from fifteen to fifty fathoms. It is taken from all types of bottoms except, perhaps, oozy mud. By far the largest quantities are, however, taken from sandy or sand and shell bottom.

In the Gulf of Maine, scallops occur in very large quantities o the great fishing banks, particularly Georges and Browns banks. As they occur further southwards, they seem to prefer deeper water; and of Southern New England and North Carolina, where there is a considerable fishery, they occur chiefly on the edge of the continental shelf, in up to a hundred fathoms.

In the Fundy area, the chief centres of distribution of scallop are at the mouth of the Bay on the Nova Scotian and New Brunswick sides In Nova Scotia they are most plentiful off Digby, Digby Neck and Brier Island; while on the New Brunswick side, Grand Manan is probably the chief area.

To attempt to define the actual scallop-beds of the Fundy area would be quite impossible. A scallop-bed, or area of the bottom upon which scallops are found together in large number, may be anything in area from a square mile down to a few square yards; and not even the fishermen themselves, who are investigating the beds the whole time, can tell where all of them are situated. In addition to this, a scallop-bed may be in one position one day, and two weeks later may have completely shifted its position. Thus it is obvious that only a very general idea of the distribution of the beds can be given.

It appears that the chief factors in determining the presence or absence of scallops in a certain area are the type of bottom and the food available. This has yet, however, to be verified. Yet on a large area of shell-sand--say twenty square miles--the scallops will be found not by any means evenly distributed. The beds will be scattered here and there, with extensive stretches of apparently perfectly good bottom between them, from which not a scallop can be dragged. Thus it can be seen that, if a fisherman is to make a success of scalloping, he must have the bearings of the actual bed upon which he is dragging very accurate.

In this report, it is proposed merely to designate the chief scalloping areas in the Fundy region, upon which beds of scallops are to be found in commercial quantities. It has been considered best to follow the outline of the Bay, beginning on the northern side at the International Boundary and ending at the Shelburne County line, Nova Scotia, and discussing the various known scallop areas in sequence.

It is impossible to obtain an accurate picture of the actual distribution of scallops from the material supplied in the Canadian Fisheries Statistics, since these only record the places of landing. Since, however, the boats do not generally go far from their ports to drag, these statistics may be said to give a general picture. To ascertain the actual distribution it is necessary to know the position and size of the beds that are fished, together with that of the ones that are there, but have not been fished. Regarding the latter problem, we are fortunate in having received great assistance from the results obtained by Captain A. E. Moore of the "Nova IV", a lobster-boat from Halifax that was commissioned by the Government during the summer of 1931 to investigate the scallop resources of the Bay of Fundy. His results, coupled with the statements and rough sketches of the scallop-fishermen, as to the position and size of the beds already fished, present a fairly clear picture of the scallop distribution in the Bay. Investigations have also been carried on at various times in the past along the southern shore of the Bay, and the results of these have also proved very helpful.

Outline maps, traced from U.S. chart No. 610 of the southern half of the Bay of Fundy (Figures 9 - 11), upon which have been drawn the approximate sizes and extents of the known scallop areas, are given in order to convey as accurate a picture as possible of the scallop distribution. The beds are numbered according to the following series for easy reference. It must be remembered, however, that it is impossible to define the limits of a scallop area by an abrupt line, as the scallops may grade off slowly at the edge of the area. Hence, in these maps, although scallops may be found outside the limits indicated, they are not found there as far as is known in marketable quantities. Scallops are indicated in these maps by stippled areas.

In general, the Fundy areas are in two main groups--those around Grand Manan and those off Digby. The Grand Manan scallop-beds may be conveniently classed as old beds and new. The old beds have been nearly fished out in the past, and consist of four principal ones:

(1) Green Island Bed:

South of S. Green Island, in an E.S.E. direction nearly to Long Point, Whitehead Island. Depth ten fathoms. Bottom sand and rocks. In the estimation of the scallop-fishermen of Grand Manan, this bed was "worth all the others put together". Now almost barren, and hardly worth dragging.

(2) Three Islands Bed:

Extending down the eastern side of the largest of the Three Islands. Depth about ten fathoms. Bottom sandy. This bed is also not worth dragging now, since in past years it has been fished extensively.

(3) Whitehead Island Bed:

Extends down the eastern side of Whitehead Island, from half to one and a half miles off shore. Depth, eight to sixteen fathoms. Bottom, sand, shells and rocks. The western portion of this bed was fairly productive in 1930 and 1931, but to the east there are too many rocks for successful dragging. Captain Moore investigated this bed during summer, 1931, using one team of three drags, each three feet across; and he obtained from five to ninety scallops each drag. This is not very good dragging from the commercial viewpoint.

(4) Duck Island Bed:

Existed to the south of Big Duck Lodge, extending in a W.S.W. direction nearly to Whitehead Island. Depth, nine to ten fathoms. Bottom, sand and shells. It has been fished too extensively in the past to be much good now. In 1931, however, considerable numbers of fairly young scallops were dragged on this bed.

The other group of Grand Manan scallop-beds, the recent ones, consists of three beds discovered by Captain Moore during the summer of

1931. They are mostly situated in the somewhat dangerous region of the Murr Ledges to the south of Grand Manan; and can only be dragged during the best weather.

(5) <u>Gannet Rock Bed</u>:

Bearings: Gannet Rock S.E. ½E.
Long Ledge W.

Depth, 10-22 fathoms. Bottom, sand, shells and a few stones. This is the largest of the three beds. As far as it is possible to judge from the draggings taken, it is about three miles long by three-quarters of a mile wide. It extends from Cross Jack Ledge in the Murr Ledges up north of Gannet Rock to Kent Shoal and partly around the N.W. side of the latter. From the catches of scallops made by the "Nova IV", it would appear that this is a fairly good bed, the scallops taken being quite large and well-meated. The maximum drag on this bed brought up 420 live scallops, and this is considered by the fishermen to be good. Nearly every drag brought up over 200 scallops.

It is noted with interest that about fourteen years ago, Captain Len. Guptill of Grand Manan, an experienced scalloper, dragged over the very same bottom on which this bed is situated, hoping to find scallops. He found none. This indicates that the present bed is a comparatively new one, and the probability of it lasting out well would appear to be great. Possibly the scallops have migrated to this area from elsewhere, and finding conditions well-suited to their requirements, have stayed. Captain Moore's results are appended (Figures 12 and 13).

(6) <u>Murr Ledge Bed</u>:

Bearings: West Ledge N.W. ½ N.
Gannet Rock E. by E. ¼ S.

Depth 9-21 fathoms. Bottom, sand, stones and shells. This bed is smaller than the foregoing one, extending down the eastern side of Long Ledge between that and Cross Jack Ledge for a little over a mile, being about half a mile wide as far as can be judged from Captain Moore's draggings. The scallops are apparently well-meated. The prospects for this bed are also good, since as many as 322 live scallops were obtained in a single haul by the "Nova IV". The scallop-fishery of Grand Manan is such, however, that newly discovered beds do not remain productive for very long because of their small size, the ease with which bearings can be taken accurately, and the concentrated fishing that invariably takes place on the discovery of such beds. Captain Moore's dragging results are appended (Figure 13).

(7) <u>North Rock Bed, Machias Seal Island</u>:

Bearings: on the N.E. side of North Rock, as close as the boat can drag. Depth averages about 15 fathoms. Bottom patches of sand and scallop shells among rocks. There is a wreck on this bed, close in to the rock. This is the smallest of the three beds, being approximately ½ to ¾ miles square. The scallops on this bed were, in 1931, for the most part, young ones with good meats. Up to 285 scallops per drag were obtained here then by the "Nova IV". (See Figure 12).

The seven beds considered so far are the chief ones known to exist around Grand Manan. Scallops are found off the northern end of the island in small numbers, but are not plentiful enough for a fishery.

(8) <u>Campobello Island</u>:

Fourteen years ago there was quite a large fishery for scallops from Wilson's Beach. Nearly all the dragging was done by hand with single drags of various patterns which were somewhat flimsy in structure compared with those now used at Grand Manan and Digby.

The bed that in past years has produced most of the scallops landed on the island is situated towards the southern end of Herring Bay, off the "Raccoon Ledges", in quite shallow water (about seven fathoms), and hard bottom. Captain Moore, however, dragged in this area in 1931 and found no scallops worth fishing for. Apparently the bed does not exist at the present time, probably due to over-fishing in the past.

Scallops are frequently taken on trawl-lines all the way up to Head Harbour from Herring Bay, and again on the southern to eastern sides of Spruce Island. In the latter place, the water is about 40-50 fathoms deep, and the bottom too rocky for dragging. Some very large scallops are taken here on trawl-lines.

A small bed of scallops used to exist on the south side of Sandy Island in 18-20 fathoms of water. Captain Moore did not find any here.

(9) White Horse Island Bed:

Situated between White Horse and Bliss Islands, in 20-25 fathoms of water, a small bed was discovered by scallops being caught on trawl-lines, and was fished during the winter of 1933-4. Most of the scallops taken were small.

Captain Moore obtained a few very large scallops W. of Barn Island. They were not plentiful, however, and mostly too old.

(10) West Quoddy River:

Off Clam Cove Head, extending from about 200 yards off-shore in the channel, practically across to the American side. Depth 20-40 fathoms. Bottom, sand; rocky inshore. This bed was discovered during the winter of 1933-4, and due to its sheltered nature, was extensively fished during the winter and spring by boats from St. Andrews, Campobello and Eastport. The probability is that this bed will be shortly fished out, owing to its convenient position, close to several fishing ports.

(11) Passamaquoddy Bay:

North and N.E. of the McMaster Island, about half-a-mile from the island, at the entrance to Letite Passage. Depth, 30-35 fathoms. Bottom, sand and scallop-shells. This bed, which is not very great in extent, was also discovered and intensively fished during the winter of 1933-34; so much so that, during the summer of 1934, when the Biological Board boat "Sagitta" tried dragging the bed, practically no scallops could be obtained.

(12) The Wolves:

Bearings: From west end, East Wolf, to west end, Spur Wolf, N.W. side, depth, 14-39 fathoms. Bottom sand with a few stones. This is another bed discovered during 1931 by Captain Moore on the "Nova IV". Up to 350 live scallops per haul of the drag were obtained. All these scallops were very young, however, and a very large percentage were too small to be marketable. During the winter of 1933-34, when repeated discoveries of new beds on the New Brunswick side of the Bay spurred the fishermen to great efforts in dragging, this bed was fully exploited and yielded a large percentage of the total catch, although the dragging did not leave much of the bed.

(13) "Thomas Lord's Reef":

Extending from Point Lepreau nearly to Eastern Wolf. Depth, 22-34 fathoms. Bottom, muddy, with patches of sand and stones. Scallops occur locally, and were largely dragged up during the winter of 1933-34, although some remained for the fishery the following winter. Scallops were taken here frequently on trawl-lines. "The bottom is too muddy, however, for scallops to be present in large numbers" (Inspector of Fisheries, Justason).

(14) Mace's Bay:

On a line from Seeley Point to Point Lepreau, in the centre of Mace's Bay, lies what was in past years a large and very productive scallop bed. Depth, 11-15 fathoms. Bottom muddy. In recent years this bed has played out somewhat and not many scallops are taken from it now. (Inspector Justason). Captain Moore did not obtain many here.

(15) Pope Logan Bed:

East of Logan Point, off Pope Logan Island, there lies a small scallop-bed that has been fished extensively in the past. Depth, 5-15 fathoms. (Inspector Justason). Bottom, stones and mud, mostly. Captain Moore obtained a few scallops here, but they were not numerous.

(16) L'Etang Harbour:

Bearings: within the Harbour, extending from the S.E. side of Cailiff Island up to the N.E. end of L'Etang Passage. Depth, 8-14 fathoms, deepest in the centre. Bottom varies: off Cailiff Island it is composed of stones and shells; in the Passage it is muddy; at the N.E. end of the Passage it is stony, with many shells. This bed has periodically been quite productive in the past. The scallops are most abundant in the area off Cailiff Island and on the S.E. side of the Passage, close inshore. A few scallops are found on the south side of Park Island in very shallow water (2½-5 fathoms). (Captain E. Rigby). This bed is fished by local fishermen with single drags.

North Shore of Bay of Fundy:

Contrary to the belief of many of the Grand Manan scallop fishermen, there appear to be no scallop areas along this part of the coast, this being amply demonstrated by the results of Captain Moore's draggings on the "Nova IV". He found no scallops whatever from Point Lepreau all the way to Spicer's Cove, including Quaco Ledges and Chignecto Bay. The bottom in general was too muddy for scallops. From Spicer's Cove to West Advocate from 5-20 scallops were taken in some hauls of the drags.

The Minas Basin and Vicinity:

There is no regular fishery for scallops in this area, but in the "Fisheries Statistics" for 1920, 1921 and 1922, a few scallops are credited to Cumberland County, Nova Scotia. Upon investigation it was found that at this time six boats had operated here from Grand Manan. They found a few scallops in Advocate Bay. It was only a small bed, and has not since proven to be productive. Harvey Merriam, of Port Greville, went to considerable expense fitting out his boat for investigation; but lost his gear by fire.

Occasionally scallops have been found on the Parrsborough Shore; and during the great storm of 1927, many living scallops were cast up by the waves on Cape Blomidon. Possibly these came from off Boot Island. Arthur Spencer, of Windsor, tried dragging for scallops in White Waters, south of Cape Blomidon, but only two living scallops were obtained. The results of the "Nova IV" investigations in this area bear out the foregoing remarks: scallops were taken only in very small numbers in Advocate Bay.

Hall's Harbour to Port Lorne:

Captain Moore dragged inshore and offshore from Hall's Harbour to Port Lorne, finding no scallops as far as Margaretville, and a very few, of little commercial value, from there to Port Lorne.

(17) Hampton to Parker's Cove:

A good area of scallops exists all the way from Hampton to Parker's Cove, from one to six miles off shore, being about twelve miles in length. Depth, 24-42 fathoms. Bottom mostly sand and shells. According to Captain Moore, who determined the position and size of this area, the scallops are well-meated and of fair value.

This area may be looked upon as the eastern extremity of the extensive scallop grounds that lie all along the coast down to the S.W. of Brier Island. Scallops are found all along this coast on sandy bottom except between Moore's Ledge and Sandy Cove, the "beds" being but areas in this region, where the scallops are present in greater abundance than elsewhere.

(18) Hillsburn to Digby Gut:

Three-quarters to three miles offshore. Depth, 25-45 fathoms. Bottom, sand and stones. This large scallop area embraces the "Horseshoe Shoal", which is three miles N.E. of Point Prim. Captain Moore found that the average number of scallops per drag taken on this bed was about 60 (1,000-yard drags), but they are, of course, much more abundant locally than this. The scallops are well-meated.

(19) Delap Cove Area:

Five miles off-shore, opposite Delap Cove, there is another bed of scallops, smaller than the last, being about four miles in length.

Depth, 38-40 fathoms. Bottom, sand, Average number of scallops per 1000-yard drag, 105 (Captain Moore).

(20) The Snow Grounds:

Named after Captain Ansell Snow, the discoverer of the bed, which is one of the largest and most producive of the Fundy beds. Eight to nine miles due north, Point Prim. Depth, 29-40 fathoms. Bottom, stones and gravel. A very productive bed in the past, and apparently one of the chief sources of scallops for the Digby fishery. The scallops are not very large, but are abundant. The bed is still very productive and during fine weather is the scene of perhaps the most active scalloping on any area.

(21) Yankee Bank:

Twelve miles due N. Point Prim. Depth, about 50 fathoms. Bottom, sand and shells. An unexploited area here is very productive of small scallops, which are extremely abundant. This region is separated from the Snow Ground by a region where the Horse Mussel (Modiola) is the predominant form.

(22) Ledge Shoal to opposite Sandy Cove:

Commencing at Ledge Shoal (three miles N.W. by W. of Point Prim) a very large scalloping area extends all the way down to a point opposite Sandy Cove, Digby Neck, at a distance of ½-4 miles from shore. Depth average, 35 fathoms. Bottom, sand, shells and a few rocks close in shore. This area is very productive; but since the scallops on it are very localized in their distribution, being found in scattered beds, the scallop-fisherman has to be very experienced to obtain the best results. The best portions are situated opposite Gulliver's Head, Trout

Cove and Sandy Cove, up to eight bushels per drag being taken at times three miles N.N.W. of Gulliver's Head.

Sandy Cove to Moore's Ledge:

Bottom, rocky. Captain Moore's results agree completely with those of the many Digby fishermen who have tried to drag scallops here: there are none. Why this should be is not clear, for certainly the bottom is excellent for scallops at some points in this area.

(23) Ridge Shoal:

Six miles N.W. by W. of Point Prim. Depth, 37-45 fathoms. Bottom, gravel and stones. A scallop area extends parallel with the coast for about five miles from this point to opposite Gulliver's Head. Scallops good, and plentiful, though somewhat local in their distribution.

(24) Annapolis Basin:

A small bed of scallops exists off Victoria Beach at the inner end of the Gut, extending into the Basin. The scallops on this bed are very large and well-meated. This bed was the first one discovered in the vicinity of Digby in 1920, and has been fished very intensively in the past, due to its sheltered nature. So intensively was it fished, that in 1930 the Annapolis Basin was closed completely to scalloping for a period of five years. In February, 1935, the season was re-opened for one month; but the dragging proved to be very unproductive. It is probable that this area will have to wait for an exceptional set of spat before it regains its former quality.

(25) Moore's Ledge, Brier Island:

Bearings: North Point, S. x W. ½ W. to S.W. ½S.
Boar's Head, Long Island, E.N.E. to N.E. by E.½ E.
Depth, 20-47 fathoms. Bottom, stones, sand and rocks. Though not very

large, this bed has been, and is, a fairly productive one. The scallops are comparable to those in the Annapolis Basin as to size and quality. It used, when the price of scallops was high, to pay the fishermen well to come down from Digby and fish for them here. This bed extends from Moore's Ledge to Frenchman's Elbow.

(26) Whipple Point, Brier Island:

West of Whipple Point 10-13 miles. Depth 44-55 fathoms. Bottom, sand with a little gravel. A large bed of scallops about two miles wide was located here by Captain Moore. The scallops are very fine, well-meated and plentiful. Up to 377 were obtained per drag. The relative amount of living scallops to empty shells was also very large.

(27) South-west of Brier Island:

S.W. Brier Island 10-18 miles. Depth, 37-49 fathoms. Bottom, sand. Another large and slightly less productive scallop area was located ten miles S.W. of the island by Captain Moore; and found to extend to 18 miles S.W. of the island by Captain Cousins of the "Arleux" during the summer of 1935. The scallops were very fine ones, and the bottom very good for dragging. There is, however, a strong tide here, which at times renders dragging difficult for low-powered boats. Up to 240 scallops per drag were taken by Captain Moore.

No scallops are found in St. Mary's Bay; the bottom is too muddy.

(28) Lurcher Shoal ("Scallop-Grounds"):

Eight miles W.N.W. of Lurcher Lightship. Depth, 47-60 fathoms. Bottom, gravel. A few scattered scallops were found here by Captain Moore. These are, however, of little value, and the long distance from the mainland tends to discourage exploitation, only the larger boats being able to operate here. Nevertheless, there is reason to believe that somewhere in this area very extensive scallop-beds exist; they have not yet been located.

Apart from the Lurcher Shoal, no scallops appear to be found off Yarmouth County, due primarily to the rocky nature of the bottom. Rumours of vast beds of scallops existing in the middle of the Bay of Fundy have long been prevalent among Digby scallop-fishermen, and scalloping there has been attempted several times with very little success. The necessity of procuring large, expensive boats and gear for this purpose has made it prohibitive for most of the fishermen.

Captain Moore dragged for scallops on Ingalls Bank (Point Prim S. by E. $\frac{3}{4}$E., Point Lepreau N.W. $\frac{1}{2}$ W.), but found none, contrary to a belief of some of the Digby scallepers, that scallops were to be found there.

Apart from this, it may be said that the bottom of the Bay of Fundy, from roughly fifteen miles off the Nova Scotia shore, is largely mud; and scallops are not to be expected from such bottom.

At this point, the question may not too prematurely be asked, what conditions determine the distribution and abundance of scallops in the Bay of Fundy? As to distribution, several explanations suggest themselves. Scallops are found roughly all along the coastal water of Nova Scotia as far as Hillsburn, being plentiful up to Parker's Cove. Further up the Bay they are scarce. On the northern side of the Bay they are also scarce at the head, but from St. John down to the mouth they are, as on the Nova Scotian side, abundant. The more than coincidental correlation between this distribution and the general movement of water in the Bay suggests immediately that the water currents play a large part in determining the distribution. The general movement of water in the Bay (the resultant of ebb and flow tidal currents) is up the Nova Scotia coast as far roughly as Digby or Parker's Cove, across to St. John, and down to the mouth of the Bay again past Grand Manan, thus virtually omitting the head of the Bay. The first stages (trochophore and veliger) of a scallop's life take place in mid-water. It is obvious that the free-swimming larval stages will be carried along by the current, and when the time comes for them to settle on the bottom, it is possible, depending upon the suitability of the new environment to their development, that a new scallop-bed may be formed at this spot. This indicates that scallop-beds are likely to be found in the direct line of current around the Bay of Fundy, always taking into consideration the fact that the bottom must be suitable for development. This, as I have indicated, is found to be the case (Figure 14). The fact that no scallops are found in the middle of the Bay and along much of the New Brunswick coast-line, can be attributed to the fact that in these places the bottom is distinctly unsuitable for scallops. Thus currents and bottom are probably the major factors in determining the distribution of scallops in the Bay. Apart from these, the scallop is almost peculiar among bivalve molluscs in being able to swim quite actively through the water by the sudden opening and shutting of the valves of its shell. It is believed by a great many scallop-fishermen, and on very substantial evidence in some cases, all around the Bay, that scallops often migrate from one spot to another. They are certainly able to do so; though just how great can be their range of movement is not known.

What induces them to undertake such sudden migrations is not definitely known, and is an interesting problem for investigation. Lack of suitable microscopic plant or animal food, unsuitability of the bottom, unfavourable temperature or salinity conditions, disturbance by dragging and predatory fish, must all take a part. Both codfish and haddock are found off Digby and Grand Manan, quite often to have their stomachs full of young scallops. In British waters, Pecten opercularis, a related species, forms perhaps the chief food of the wolf-fish, Anarhicas lupus, a species occurring in the Bay of Fundy.

As to what determines the abundance of scallops in the Fundy area, little if anything is definitely known. Subsequent research upon Digby scallops, coupled with the fact that upon any bed of scallops in the Bay there seems almost invariably to be one greatly predominating age-group, which may vary in its age, from place to place, leads us to suspect that the most important factor is the relative success or failure of the spawning season. This, however, is probably a very complex problem linked up with food-abundance and a variety of other factors that tend to promote or decrease the success of spawning, the amount of eggs spawned, and the survival of the larvae after their free-swimming stages.

6. FISHERY IN THE PAST

The first account of the scallop-fishery in the Bay of Fundy, we find in Perley's "Report on Fisheries in the Bay of Fundy", 1851 (6). On page 123, he says: "With regard to scallops, it may be stated that they are frequently taken, in considerable quantities, and of the large size mentioned by General Dearborn, at Mace's Bay, north-west of Point Lepreau, where extensive beds of this peculiar shell-fish are known to exist. Of late, the edible portion of these large scallops has been put up by a noted preserving establishment at New York, and sold in glass bottles at a high price as an unusual luxury. They are much esteemed, and sell readily; so this branch of business is open to the people of New Brunswick, who have a large supply of scallop, easily accessible".

His suggestion has since been carried out, and a fishery of large proportions has grown up in the Bay of Fundy.

On page 160, he mentions, when writing of the Annapolis Basin, that "there are extensive beds of scallops". Apparently, although there was no fishery for them, scallops were known to exist in the vicinity of Digby even then.

T. F. Knight, in his "Nova Scotia Fisheries" (1867) (7), mentions scallops as being "common to the whole coast of Nova Scotia, but abound on sandy beaches......" He was probably exaggerating somewhat in this latter statement, since Placopecten, the only common species, is typical of deep water and not of beaches.

Two years later, the "Fisheries Statistics" were commenced, a record being kept of all landings of fish for sale. From then up till the present time, the best picture of the growth of the Fundy scallop-fishery is to be obtained from these statistical records, supplemented by the reports on fishing conditions by the Fishery Inspectors. From 1869 to 1894 not a scallop was recorded in these statistics for the Fundy area. This does not mean that none were taken. Plenty must have been hooked-up on trawl and hand-lines. These were probably eaten on the spot, or taken home by the fishermen for their own consumption.

The first recorded landing of scallops for market in the Bay of Fundy was in 1895, when about 133 barrels ("4,800 cans") of scallops were landed in the area between Back Bay and Lepreau, and canned. From then until 1901, steadily increasing quantities were landed from this and other areas, and practically all of them were canned. According to the reports of Inspector J.H.Pratt (Fishery Inspector's Reports, 1896), this business of canning scallops would have been more extensive but for the "prohibitory duties imposed by the United States Tariff" at that time on canned goods.

In the accompanying graph (Figure 15) it can be seen that the course of the scallop fishery from 1901 to 1920 was fairly uneventful. A peak was reached in 1908, when 3,175 barrels of scallops were landed. Three years later, however, this had decreased to nothing, probably because the known scallop areas had been fished out. All the scallops recorded for the Fundy area in the "Fisheries Statistics" prior to 1920 were taken off Charlotte County. In 1914, 150 cwt. were credited to Digby County, Nova Scotia, but these were taken on the Campobello beds, New Brunswick.

By 1920, the New Brunswick fishery had reached a low ebb, nothing being landed in that year, and only 20 barrels in the year previous. This was partly due to the fact that the beds, which were not very large, had been just about fished out, and no new ones had been discovered to take their place. It was in 1920, however, that the real Fundy scallop-fishery began. Certain Digby fishermen, Roland Wormell and Arch. Amero among the foremost, had discovered a very productive bed of scallops in the Annapolis Basin. This was fished assiduously for the next few years by a steadily growing fleet of scallop-boats, and great quantities, far exceeding any taken on the Charlotte County beds, were caught and landed. Conditions were good and a high price could be obtained. This price fluctuated greatly from time to time, the yearly average being as high as $6.93 per barrel (in 1926), and as low as $4.48 (in 1922). Fifty dollars clear profit for one trip was quite a common occurrence. It must be remembered, however, that it was by no means on every day that the scallopers could venture out. Sometimes the weather would be too bad for as long as ten days at a time for any scalloping to be attempted. Bad weather and high seas cause the drags to "jump" along the bottom without picking up many scallops. Since the scallop season was during the winter time, there was plenty of this bad weather.

Soon after the discovery of the Annapolis Basin beds, some ofthe more enterprising scallopers tried dragging outside Digby Gut in the Bay of Fundy. There, to their surprise, they had great success. Beds of large extent were found to exist there, and it was not very long before the fishermen located the most productive ones, and fished them extensively. Boats from Digby, Victoria Beach, Bay View, Parker's Cove, Hillsburn, Sandy Cove and Centreville took part in the fishery. In 1922, 48 boats were in operation from Digby County, each with a set of drags. This total increased to 90 in 1926. In 1927, Annapolis County had 16 boats in the fishery; and even Yarmouth sent up two boats, which fished the new beds just discovered off Brier Island.

It is natural with a "quick" fishery such as this, that measures should be taken to conserve the resources. Soon after the fishery began in 1920 a close season was placed upon scallops. This stopped the fishery for them during part of their spawning period, and extended from June 1st to October 15th inclusive.

In order to prevent the taking of large quantities of very young scallops and seriously depleting the future stock, a size limit of four inches was also imposed, under which none could be taken. This size-limit regulation is, however, very difficult to enforce, since the scallops are generally shocked immediately they come aboard, and the shells are thrown overboard. The fishery regulations for Nova Scotia regarding scallops, as they now (1935) stand, are as follows:

Section 19:

1. No boat shall be used in scallop-fishing nor shall anyone leave any port or place in the province to fish for scallops, either inside or outside territorial waters, except in a boat that is under license from the Minister. The fee on each such license shall be one dollar.
2. No one shall fish for scallops in territorial waters from the first day of June to the fifteenth day of October, in each year, both days inclusive, and in extraterritorial waters from July fifteenth (This year, 1935, this was changed by the Department to June fifteenth, to stop the great increase in landings of scallops) to October fifteenth in each year, both days inclusive.
3. No one shall fish for, catch, kill or sell any scallops measuring less than four inches in diameter across the wider portion of the outer shell, and any scallop of a less size taken accidentally shall be returned alive and uninjured to

the bed from which it was taken by the person catching it.

4. The meshes of scallop rake bags shall consist of wire rings or twine of not less than three inches in diameter.
5. The waste portion of scallops shall not be thrown overboard from boats on the scallop fishing grounds.
6. The practice known as "floating" or "soaking" scallop meat in fresh water is prohibited.
7. Scallop fishing in the waters of Lunenburg County shall be permissible only from the first day of November in each year to the thirteenth day of the April following, both days inclusive.
8. Scallop fishing shall not be permissible in Digby Basin (= Annapolis Basin) until February first, 1935. Such fishing shall thereafter be restricted to the month of February in each year.

It will be seen from the last of these regulations that steps have been taken to stop overfishing in the Annapolis Basin. The beds there are the most easily accessible, and bad weather conditions are not so effective in stopping the fishing, due to the sheltered nature of the Basin.

During the winter of 1934-5, the Digby scallop fishery reached its highest peak. At the time of writing, statistics are not available; but it appears that the catch during the winter was several times as large as the winter preceding, when 27,512 barrels, valued at 108,478 dollars, were landed in Digby and Annapolis Counties. Scalloping there has been one of the most profitable of fisheries, and more and more fishermen have taken it up. A high peak in the landings was attained in 1927, but in 1928, due to a very marked fall in price caused among other things by the discovery and exploitation of vast scallop areas on Georges, Browns and other great fishing banks, and the consequent glut on the American markets, the landings of scallops in Digby and Annapolis Counties fell somewhat. Yarmouth dropped out of the fishery. In 1929, the decline due to increasing American competition was even more apparent; and conditions during 1930 and 1931 were much the same. The fact that most of the scallops taken off Digby are shipped via Yarmouth to the Boston and New York markets, where they are more readily sold than elsewhere, causes this competition to assume a serious aspect. Boats leave Boston equipped with large dredges up to twelve feet across, two of which they haul along the bottom at the same time. Such boats often come into port after a trip to the banks, with as many as 1,400 gallons of scallop meats aboard. We are told that in some cases as many as 4,000 gallons per boat per trip have been landed. With such quantities to sell, the promoters of such enterprises are willing to accept as low as 80 cents per gallon on their catches. Canadian scallop-fishermen find scalloping too expensive a trade to sell their scallops at as low a price as this, and hence it is only when the American boats are away at sea, or when it is too rough on the banks for them to operate successfully, that the Canadians can obtain a good price.

About $1.50 per gallon is as low a price as Canadian fishermen find it profitable to accept for scallops.

The course of the Digby Annapolis scallop-fishery, together with the general fluctuations in price obtained, as denoted by the "Fisheries Statistics," is shown in Figure 15.

The yearly landings of scallops during the forty-one years that have passed since the Fundy fishery began, have been by no means constant, as is shown by Figure 15, in the curve representing the whole Fundy area. When a new bed has been discovered, there has been a vigorous fishery for a year or two until the bed has been fished-out, when the curve drops very low. Another bed is then discovered elsewhere, and the curve again rises for a period. The apparent fluctuations seem to have been influenced more by the discovery at intervals of new resources than by anything else. In the Charlotte County, N.B. statistics, for instance, from 1895 to 1901, far the greatest quantities of scallops are shown to have been taken in the region between Back Bay and Lepreau. These dwindled to nothing in 1905 between Red Head and Lepreau, but in the meantime the region between St. George and Red Head was landing increasing quantities. These gradually dwindled to nothing at all in 1911. In 1914 a big fishery began off Campobello, which also gave out by 1920. Grand Manan has also periodically produced scallops in large numbers. In 1903-1905 it produced more than any other region in the Bay of Fundy. In 1913; 1918 and 1921 fairly small quantities were also landed on this island. Again, in the years 1923-1925 large quantities were landed in Grand Manan; also in 1928-1931. An upward rise in the curve takes place in each of these instances.

Apart from the discovery of new areas of scalloping ground, the main factor in determining the production of scallops in the Bay of Fundy appears to be price. It is apparently only during the last seven or eight years that, due to American competition, price has become the important factor. In the earlier years of the fishery, no difficulty was had in selling scallops at a fair price, simply because the demand remained on the whole steady, and the competition relatively insignificant. With increased competition, however, the price obtained by the fisherman has fallen--so far, in some cases, that they have not found it worthwhile on certain occasions to drag for scallops.

During this summer (1935), however, some of the Digby scallopers have informed me that they believe, due to much overfishing on the banks, the American competition promises to be not such a serious factor in the future as it has been in the recent past. Whether there is anything to this, remains to be seen. The Fundy scallop-beds must be carefully conserved if Canada is to retain this valuable natural resource for long.

7. THE UTILIZATION OF SCALLOPS

For convenience, scallops may be divided into three main parts: the meats, the waste flesh ("Rims"), and the shells.

The Meats:

This consists of the adductor muscle, and is at the present time the only part of the scallop used as human food in Canada. This is the most valuable portion, and has been known to fetch as much as six dollars a gallon at Digby.

Digby scallops used to be landed at the Quay "in shell", where special workmen were ready to "shock" (or "shook") them, during the time of high prices. With the fall in price, most of the shocking is done aboard the boats before landing, all hands taking part between drags, and speed being maintained by the men racing each other as to the quantity of scallops they can shook before reaching port. The process consists of removing the meat from the rest of the scallop; and some of the experts can fill a pail with shocked meats in 45, or even 35 minutes. The scallop is held in the left hand of the shocker, flat shell downwards and beak outwards. The shocking knife is then inserted between the shells on the right-hand side, and is so manipulated that it severs the adductor muscle as close as possible to the flat shell, when the two shells fly open. The flat shell is torn off. The "rim" is now taken between right thumb and knife, and ripped out of the shell. It takes considerable practice to be able to do this without injuring the meat, which is left standing in the rounded shell. The knife is used again to separate it from this valve, and the meat is dropped into a bucket, nearby for the purpose, the rim being thrown into a tub for future use or into the sea. Some of the "high-line", or more expert shockers combine the two actions of removing the flat shell and the rim into one; but this takes some practice to achieve satisfactorily. Some increase in speed can be attained in this way; and when men are receiving 50 cents a bucket for shocking scallops, this makes some difference.

Shockers usually receive about 50 cents for every bucket they fill with meats. A bucket such as this contains about two gallons of scallop-meats.

Barrels are now obtained ("Herring half-barrels"), in which the meats are packed (with ice if the weather is at all warm). They are then trucked to the station, and are sent by express train to Yarmouth; and from there to Boston or New York, or wherever in the United States they are to be sold. They are shipped aboard the S.S."Evangeline" and other boats plying between Yarmouth and the United States. They are sent so that they will arrive in time for market the next day. Here they are sold, and later disposed of by the various buyers.

Most of the scallops that are taken in the Fundy area are sold fresh (shelled). In the earlier years of the fishery, large amounts were canned, but this has of recent years fallen off greatly. Since the Digby fishery began, only a few scallops have been canned (1924 - 1929). These were canned in Annapolis Royal by Beaton and Livingstone, Ltd. They constituted a very small portion (in 1929 about 15 per cent, and otherwise not over 2 per cent) of the total landings of scallops in Digby and Annapolis Counties. Ordinarily, scallops have a tendency to shred easily when canned, and Dr. Ernest Hess, of the Staff of the Fisheries Ex erimental Station at Halifax, N.S., working upon the problem, has investigated the matter. He states (8) that "a considerable shrinkage in volume and weight, and undesirable darkening of the colour of the muscle due to the time and temperature of heating necessary to sterilize the can contents and a very undesirable breaking apart of the muscle fibre bundles into shreds of fibres" are the results of canning the meats. However, further research in the matter has since then been done, and Dr. Hess finds that if before canning the meats are fried for a short period, this eliminates almost entirely the shredding, and a very satisfactory product is the result (9).

Dr. Hess also tried the effect of rapid freezing of scallop-meats in brine. The results were very satisfactory, and the frozen meats upon thawing could not be told from the fresh meats.

Fresh scallops are eaten by various people, fried, stewed or creamed, according to taste. Many people, the writer included, consider them to be very good raw.

The "Rims":

Since they are not eaten by people together with the meats, the rims, which consist of the viscera, mantle and gills of the scallop, have been quite extensively used both in Digby and Grand Manan as bait. The fishermen say that this is one of the best baits for cod, and that dogfish and skate will not generally bite at it. It was apparently the fact that both cod and haddock are frequently taken off Digby and Grand Manan with young scallops in their stomachs, that led the fishermen first to try it out as bait. It proved so successful that at Digby the line fishermen are often willing to do the whole work of shocking for the scallopers, receiving as payment the rims they shock, for baiting their trawls. For those who are willing to buy this bait, it can be obtained at the rate of about 25 cents a bucketful.

The meat of the scallop constitutes on the average only about 25 per cent of the total flesh of the scallop. The possibility of utilizing to better advantage the other 75 per cent constituted by the rims has been considered, and Mr. Hess has succeeded (8) at the Halifax Station, in producing a very presentable paste, dark-green in colour, and tasting like lobster-paste, by combining in definite proportions the various organs in the flesh.

The Shells:

Apart from their use in houses as ornaments and ashtrays, scallop shells have been utilized in Annapolis in the production of poultry grit, for which the shells, which were obtained for the most part from the Digby wharves, were ground up. The fishermen were receiving $2.00 a ton for these old shells.

There is a peculiar variant among the Digby scallops that occurs somewhat sparsely on the inshore beds, characterized by the fact that the inner layer of the shells is coloured to a greater or less extent a very beautiful violet. Such shells are known locally as "Blue Shells", and are to be seen on sale in the Digby shops. They generally fetch about a dollar apiece, though the price ranges from 25 cents up to $1.50 (Figure 16).

Substitutes:

In recent years, with the growth in demand and price for scallops, the practice has arisen, especially in the larger markets, of punching circular pieces out of the "wings" of skate, corresponding in size to the meats of scallops, and selling these under the name of scallops. To the inexperienced eye there is no apparent difference between the real and the substitute. The chief difference lies in the fact that in real scallops the meat fibrils run longitudinally, whereas in the skate flesh they are transverse. This substitution is not practised widely enough to be of any serious consequence in the marketing of real scallops.

8. FUTURE POSSIBILITIES OF THE SCALLOP FISHERY

Although it is apparent that if the Fundy scallop fishery continues to increase in extent as it has been doing, measures will have to be taken to conserve the resource, it is believed by many of the fishermen that the fishery's future largely depends upon the future state of the market for scallops. It is therefore necessary, so that the best results may be obtained, not only to improve the marketing conditions but also correspondingly to improve the fishery conditions themselves. A greater demand should be easily created, since it is believed that the potential market has hardly yet been touched. This can be done either by advertisement or by the wider distribution of the product itself. Fresh scallops, owing to their perishable nature, cannot be distributed very widely. Brine freezing would overcome this difficulty. Although a somewhat costly method, this would enable the scallops to be transported over long distances without harm. At long distances from the sea, the probability is that the cost of brine-freezing would be compensated for by the higher price that would be realized. At the present time, the methods of distribution are not all they could be, chiefly due to the fact that the Digby scallop-fishermen are a very independent group, and have not yet been persuaded to club together over the business. The scallops are carried by train and ship in their own ice, and will not last very long. Refrigeration apparatus on special boats, whose sole duty would be to deliver fish to the American markets, would be an enormous improvement. As it is, the scallops have to be sold almost as soon as they reach the market, irrespective of the price-level. If they could be held until prices rose, they could be sold at a better profit. This could be effected by means of proper refrigeration. Delivery boats such as these, operating direct from the port of landing to the chief American or Canadian markets would also bring the fishermen into closer touch with the market.

As regards the extension of the fishery itself, it has been suggested that larger boats and gear would enable the fishermen to go farther afield. This would certainly be a good proposition if the fishermen were thinking of scalloping on Georges and Browns banks, right out to sea. It is the belief of the fishermen at Digby, however, that the boats in use in the Fundy area, which have been specially designed for the work, are ample for the particular dragging that they do, not far from their home port.

Since the beginning of the scallop-fishery, there have been many investigations in Canadian waters for new beds. The scallop-beds appear continually to be changing as to size, shape and position. It is therefore necessary to keep track of their whereabouts, although if the fishermen are continually confounded as to their distribution, it is perhaps to the welfare of the fishery in the future. Exploratory work is done to a large extent by the fishermen themselves, who know generally where the best beds are situated. The fact remains, however, that good new beds are continually being discovered, and are likely to be as long as investigations are carried on.

It is the belief of many fishermen that the more empty shells there are lying on a scallop-bed, the better the bed is. They believe that these empty shells cover up and protect especially the young scallops from such predatory fish as cod. The first few drags on a bed like this, they say, bring up very little but empty shells. As dragging is continued, more and more living scallops are brought up. It would therefore seem to be a good thing to dump all shocked shells back upon the bed, since these would replace many of the old, empty shells already on the bed, that had become rotten through the depredations of Cliona. In muddy or sandy localities, such shocked shells would supply something hard and stable upon which the scallop spat could settle.

Finally, it should be stated that the scallop-fishery of the Fundy region is a fishery, by reason of the extreme localization of the scallops, that can, if proper precautions are not observed early, be very easily over-exploited. It is therefore extremely desirable that a firm scientific knowledge of the life-history and natural history of the scallops should be obtained to provide a basis for the conservation methods that may have to be applied. It is the purpose of the second and third parts of this thesis to provide the rudiments of an outline of the growth-rate and some of the environmental relations of the Giant Scallop that will be a basis for such scientific knowledge.

PART II.

THE GROWTH OF ADULT SCALLOPS

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1. INTRODUCTION

(a) Statement and Significance of the Problem

(i) Purposes:

Since the year 1920, the scallop-fishery of Eastern Canada, particularly of the Fundy area, has increased very greatly in economic importance, largely due to the commercial exploitation of the large scalloping areas on the Nova Scotia side of the Bay, described in Part I of this thesis. Notwithstanding the relative importance of the fishery, very little work appears to have been done upon the life-history and growth-rate of the scallops. If the fishery is to be conducted to the best advantage in the future, knowledge of the life-history and of the various factors influencing the growth of the scallops in their natural habitat is essential in order that methods of conservation may be used most effectively. The nature of the Canadian scallop-fishery, as I have already indicated, is such that conservation is found to be necessary, as the past history of this fishery has shown that scalloping areas can be and have been fished out comparatively easily within a short space of time. If, for instance, it is desired to protect a certain area from overfishing until such time as it will have recuperated, a knowledge of the growth-rate of scallops is necessary in order that the necessary period of protection may be determined.

The present part of this thesis is concerned only with the growth-rate of the scallops under varying environmental conditions.

The chief purposes of the investigation have fallen naturally into five groups:

a. The correlation of certain growth-lines upon scallop shells with definite periods of time, and the formation in this way of a basis of age-determination of shells from different areas.

b. The determination of the age to which scallops live.

c. The determination of the age at which scallops in different areas attain the legal size of four inches.

d. The determination of the average rate of growth per unit of time for (1) The whole of Eastern Canada (2) Various localities on the east coast, exhibiting different environmental conditions.

e. The correlation of the growth-rate with environmental conditions in different areas.

(ii) General Natural History pertinent to the Study:

A brief outline has already been given in Part I.

After the scallop has passed the larval or veliger stage of its life-history, it settles on to the bottom of the sea, where it lies on the somewhat flatter lower valve of its shell, and remains thus for the rest of its life. Upon settling on the bottom, the young scallop generally anchors itself by a byssus of two or three short threads, which may persist up till the time the scallop has attained a size of about five inches. Such a specimen, six years old, was seen by the writer off

Gulliver's Head, Nova Scotia, when during the present (1935) summer he was engaged in dragging scallops from the patrol-boat "Capelin". The older scallops, however, never appear to be anchored by such a byssus, remaining free on the bottom. Judging from the dragging results of Captain Moore (10), the type of bottom preferred is sand or sand and gravel, although scallops may be taken on practically all types of bottoms, excepting, possibly, oozy mud.

The food of the giant scallop consists entirely of detritus and plankton obtained by straining a current of water that is caused to pass into the mantle cavity by the rapid beating of cilia. During the present summer (1935), I have examined numerous scallop stomachs from the Digby beds, and have compared their contents with the plankton immediately over the scallop-beds. Scallops appear to take into their stomachs practically everything small that is to be found in the plankton, even going so far as to take their own and other veliger larvae, copepods, the nauplii of Balanus, and pine-tree pollen grains. Needless to say, the pollen grains are not digested, since a microscopical examination of the faeces showed them still to be intact, after passing completely through the scallop's digestive system. The same is true of certain diatoms that possess stout skeletons, for example Pleurosigma and Navicula. Certain forms are apparently digested very quickly and completely, and it is presumed that these form the most important items in the scallop's food: examples of such are the Peridinians, Tintinnids, certain ciliate protozoa, and some of the smaller diatoms. It is remarkable, however, that the most common summer diatom in Fundy waters, Chaetoceras, has never been detected in the stomach contents of the

Giant scallop.

In the adult state, scallops are almost unique among Pelecypods in being able to swim freely through the water, by the alternate opening and rapid closure of the valves, the consequent expulsion of water at each snap causing the animal to progress by a series of jerks (Figure 17). If environmental conditions in one particular area are unsatisfactory, the scallops are thus capable of moving elsewhere. This is a very important factor in the study of the growth of the animals. We may, for instance, have a specimen from one locality, which shows growth-lines on its shell that are, perhaps, representative of conditions entirely different from those obtaining in the area where captured.

The valves of Placopecten are unequal in shape and intensity of colouration, the upper valves being considerably more convex than the lower, and also generally more heavily pigmented. Examination shows that both the upper and the lower valves are also marked with definitely arranged striae and grooves. These are found to be of two types: radiating and concentric. The radiating striae have their focal point at the umbo, although some extend only a short distance from the edge of the shell towards the umbo. These striae are very numerous and fine, being about one millimetre apart at the edge of the shell, and considerably closer together at the umbo.

The concentric striae, which are concentric about the umbo, are very much fewer in number and less distinct than the radiating ones. They vary somewhat indistinctness and in proximity to each other. This is most easily seen when a scallop shell is held at some distance from the eye, when it can be seen that, concentric about the umbo, and extending from it to the periphery, are a number of more or less widely spaced lines, or "rings". They are arranged on the shells in an unmistakably regular manner, in general being farthest apart from each other nearest the umbo, and closest together near the periphery of the shell. Since these rings are of the utmost importance in a study of the growth-rate of the scallops, a description of them is given here, at first general, later considering each separate ring from the umbo outwards, in the light of the examination of many thousands of specimens during the summers of 1932, 1933, 1934 and 1935.

These rings, as are the rings in the trunks of trees, are of an annual nature. The reasons for this assumption will be taken up later. Suffice it here to say that they are deposited once a year, during the spring, at the time when the lowest water-temperatures of the year occur, thus slowing up or completely stopping the growth of the scallops.

The rings are in practically all cases formed by the concentration of the concentric striae of the dermis of the shell. These striae are, between the rings, up to 0.8 m.m. apart; but in the proximity of the rings, they are considerably less, particularly on that side of the ring closest to the umbo. During the fast-growing (earlier) period of the scallop's life, a ring is merely a slight concentration of the striae, and due to this, is not always very discernible; particularly is this so in specimens in which the striae are not very pronounced, for scallops vary considerably in this respect. It seems, to judge from the proximity of the striae in rings near the umbo and near the periphery, that young scallops do not tend so much as older ones to have a complete cessation of growth during the low-temperature period of the year. The outer rings on the shells of scallops, from the third outwards (assuming that nearest the umbo to be the first), are in general more clearly defined and abrupt than those nearest the umbo; seeming to suggest that as the metabolic activity of the scallop decreases with age, the cold weather more and more effectively manages to stop growth completely for a time in the winter.

The First Ring:

This is often a difficult one to recognize, though in some samples it is clear enough. Its clarity seems largely to depend upon the locality from which the shells have been taken, and the degree to which the dermis of the shell has been destroyed or obliterated by Cliona, or by age, or by wear and tear. The striae that go to form it are fairly disperse from 0.1 to 0.5 m.m. apart. In this way, it is sometimes difficult to tell actually which point is the centre of the ring-mark, since the region of concentrated striae, which might grossly be taken as the ring, often covers up to 3 or even 4 m.m. In such cases it is necessary to examine the ring very carefully, if necessary with a lens, to detect the actual point at which growth was slowest. The difficulty may also be overcome sometimes, particularly in shells that are thin and not too old, by holding up the shell to the light. Very often, the region extending from the umbo to the first ring, representing the first year's growth, is quite deeply pigmented, sometimes with a mottled pattern; and the region of pigmentation is generally sharply defined along the first ring. However, for the detection of the first ring, examination by transmitted light is not generally so satisfactory as by reflected light.

The Second Ring:

This is usually more clearly defined than the first, and in some samples, particularly some shells from off Gulliver's Head near Digby, was invariably very easily detected. As in the first, the striae that form this ring may be dispersed over as much as 4 m.m., and care has to be taken in determining the actual point of slowest growth. Growth during the summer immediately previous to the deposition of this ring has been the most rapid that occurs during the life of scallops from most localities. Generally the shell between the first and second rings, representing the growth during the scallop's second summer, is wide and smooth, with few of the incidental check-marks, caused by various great or small shocks, that occur in the later ring-spaces. This helps considerably in the detection of the second ring.

A characteristic of the second, third and fourth rings, in the majority of scallops from the Fundy region and from Mahone Bay, N.S., is that from immediately after the formation of the ring, up to perhaps 3 m.m. farther out on the shell, the scallops deposit a pigmented, reddish-brown ring concentric about the growth-ring immediately previous, and perhaps as much as 2.5 m.m. wide. This ring is apparently not due to decreased growth-rate, because the concentric striae are widely separated on it. In those scallops where this pigmented ring is separated from the growth-ring previous, the intervening space is generally composed of very white, translucent shell. This intervening space is not present, however, in the majority of specimens. The pigmented ring is not so characteristic of the second as of the third, fourth, and sometimes the fifth rings. It occurs fairly frequently, nevertheless, on or after the second.

The Third Ring:

The third and the fourth are generally the most easily detected of all, due partly to the frequent presence of a pigmented ring, and partly to the fact that, apparently due to complete temporary cessation of growth, the concentric striae are very close to each other, and often combine to make the ring very abrupt and well-defined.

Very often, half-way between the third and fourth rings, and again between the fourth and fifth, and the fifth and sixth, there is a raised region of the shell where the striae, though not crammed together, are very prominent. Since this region probably corresponds to that portion of the shell deposited during midsummer, it is possible that the raised portion has some relation to spawning. This is borne out by the fact that it does not occur in the young specimens (or the first two or three ring-spaces), which would be immature.

The Fourth Ring:

Is like the third, generally clearly defined, and often with a pigment ring immediately outside of it.

The Fifth and Sixth Rings:

These may be conveniently classed together, since they are very similar in appearance. Not very prominent, but nevertheless very definite. They are liable upon occasion to be confused with incidental check-marks occurring during the summer's growth between the growth-rings. Indeed, as the shell increases in size, and the proximity of the rings to each other becomes more marked, a great many check-marks, corresponding to temporary stoppages of growth from smaller and smaller shocks (it seems that as the metabolic activity decreases with age, it takes less shock to stop growth) appear between the rings.

The Seventh and subsequent Rings:

These rings are respectively more and more difficult to distinguish; and it may be said that beyond the eighth, or in exceptional samples, the ninth or tenth, the significance of readings decreases very greatly. This is due to the almost impossible task of distinguishing the actual growth-rings from incidental check-marks, and not to the indistinct nature of the growth-rings themselves; for the later rings on most shells are, in fact, quite well-defined.

Generally speaking, the clarity of the rings depends largely upon the depth of water at which the scallops live. Scallops from shallow water, such as those of the Annapolis Basin, are almost invariably characterized by a large number of confusing check-marks, probably due to the fact that in the shallow water they are much more exposed to sudden changes in the environment, such as temperature changes, which would cause such marks by influencing their growth-rate. Again, in scallops from very deep, offshore water, such as those from the Yankee Bank, twelve miles north of Point Prim, the rings of growth are always very indistinct and difficult to read. This is probably because here the molluscs are beyond the reach of small climatic changes, and the annual cycle of change in their environment is too gradual, and not extreme enough, to produce pronounced changes in growth-rate, which would be reflected clearly in the nature of the rings. The scallops with the most distinct rings appear to occur between these two extremes, in water that is too deep to be influenced appreciably by small climatic changes, yet at the same time is not too deep to exhibit a pronounced annual cycle of change. Such conditions appear to be found about three miles off-shore from the Digby coast; and here the scallops possess rings that in almost all cases are very clearly marked.

As the scallop grows, the shell increases in size by the deposition of new material on its whole inner surface, and at its edges. This deposition takes place quite evenly around the edge of the shell, which thus extends away from the umbo. Now if anything occurs that will affect the rate of deposition of the shell in this manner, the event is likely to be recorded along the entire edge of the shell, being later discernible as a more or less distinct ring that corresponds to the shape of the shell at the time of its formation. Marks like this have been found definitely to correspond with increased or retarded growth-rate under known conditions in several species of molluscs, including Pecten (Belding (11)); and a very good example of a complete temporary stoppage in growth due to the more or less severe shock of being removed from its habitat and handled considerably, can be cited for the present species. In Figure 20, it can be clearly seen where all the experimental shells (to be referred to again later) deposited a very pronounced check-mark on their shells, at the initiation of an experiment on growth that was run at the St. Andrews Biological Station, September, 1934. It is therefore quite safe to assume that such concentric marks, whether pronounced or indistinct, corresponding as they do to the general contour of the shell, are caused by a change in the growth-rate, more or less sudden as the case may be, due to a change in the environmental conditions under which the scallops are living.

(b) Review of Literature

(1) Growth in Bivalve Molluscs:

The growth of certain commercial bivalve molluscs has been quite exhaustively treated by several investigators. Weymouth (12) on the Pacific Coast, and Gutsell (16) on the Atlantic coast have both shown conclusively that a constant relation exists between the rings of growth and periods of retarded growth (in the Pismo Clam, Tivela), or the annual process of spawning (in the Bay Scallop, Pecten irradians). Newcombe has shown a case similar to that of Tivela to exist in the soft-shelled clam, Mya (13), and Orton in the European Oyster, Ostrea edulis (14); and several other species of bivalve molluscs show such cases. There is, however, practically no literature upon the growth of Placopecten. Drew(1) noted the general appearance of the rings of growth upon the shells; but went no further. Borden (15), working at St.Andrews, examined over three hundred scallop-shells and measured the distances between the lines of growth of upwards of three hundred specimens of scallops from Fundy waters. Her results showed that, as mentioned above, the interlinear spaces were widest near the umbones, and diminished in width towards the edge of the shell. Her investigation, however, was not continued long enough to produce comparative results between different areas.

It might be assumed that, due to their close systematic relationship, growth in Placopecten and Pecten irradians would be similar. Whereas Belding (11) has demonstrated that Pecten seldom lives more than two years, there is every reason to believe that Placopecten may attain an age of up to fifteen. Now the Giant and Bay scallops live in entirely different habitats--the former in more or less cold, deep water, the latter in the warm sub-littoral zone, just below low-tide mark. These differences, then, in the two forms, make it evident that a study of the growth of Placopecten, to be properly conducted, must be undertaken as an entirely separate problem from that of the growth of Pecten. Thus it will be unwise to infer that because a fact applies to the one, it also applies to the other on the grounds of close systematic relationship. The investigations upon Placopecten have led us to believe that few animals so closely related systematically could well lead as different modes of life as Placopecten and Pecten.

(ii) Methods employed in the study of Molluscan Growth:

The various methods employed by investigators in this field fall into three main groups:

The age-group method,

The annual ring method,

The experimental field method.

The present investigation is concerned with all three, and particularly with the question of the validity of the annual ring method in the case of Placopecten. In a discussion upon these methods, I feel that I cannot do better than to quote from Weymouth's classic work upon mulluscan growth, "The Pismo Clam" (12).

Speaking of the age-group method, he says: "If at any one time a large number of animals of all sizes are measured or weighed, it is usually possible to identify by a comparison of these sizes, certain of the age-groups, that is, groups of animals of the same age. In the present case (The Pismo Clam), the young clams in their first year form a distinct group easily told from those in their second year, since the largest of the one-year-olds is obviously smaller than the smallest of the two-year-olds. The difference in size between those in their second and those in their third year is less but still sufficient to distinguish the groups. With each successive year the difference becomes less marked though by careful measurements of a large number of individuals the modes corresponding to the various age-groups may be identified with varying success in different species; with the Pismo clam, this method might serve for the first four or five years. Beyond this point the method ceases to be decisive without confirmatory evidence from some other source". As time passes, the position of the mode of each age-group on the frequency curve changes, and an estimate, based upon the extent of the shifting of the modes in a definite period of time, can from this be made as to the rate of growth in each different age-group. Speaking of the annual ring method, Weymouth says that it is a method that has "been used extensively in other groups, notably fish. Here, as is well known, the evidence of unequal rates of growth at different times in the scales, otoliths, vertebrae and other hard parts has been interpreted in terms of years. According to some observers similar zones resulting from alternate rapid and slow growth may be identified at the base of the horns of cattle (D'A. W. Thompson, 1917, p. 617) and the age thus determined. In the molluscan shell the presence of similar rings has been both affirmed and denied. The validity of this method, which from the term applied to its first recognized occurrence in the wood of trees may be called the "annual ring" method, has recently been attacked on the ground that it may be an entirely physical phenomenon......"

Referring to the rings occurring in fish, Weymouth continues (p. 17): "For such marks to be of service in the determination of age, it would have to be proved:

(1) That the marks in question were distinctive in appearance and could be identified by a competent observer in the great majority of cases:

(2) That they were annual--i.e., that one and only one is formed each year. This might be established in three ways:

(a) By a definite seasonal relation of the marks to the forming margin;

(b) By the correspondence of the number of marks to the known age of animals either kept in captivity or distinctively marked and recaptured;

(c) By the agreement in number of the marks with the evidence from the modes of the age-groups".

Placopecten, by reason of the fact that it is characteristically a deep-water animal, of somewhat slow growth extending over a long period of time, does not adapt itself readily to the application of (b) above, but there is ample evidence, to be cited later, from (a) and (c) to support the theory that the ring marks on its shells are annual.

The last method for the study of growth in molluscs, the experimental field method, is concerned with the planting of living scallops marked distinctively in their natural habitat, and the observance of the actual amount of growth that takes place in a given period of time, whether short or long.

2. EXPERIMENTAL RESULTS

(a) Material Used

A number of samples of scallop-shells, from different localities on the eastern coast of Canada, were examined. They were as follows:

Sample No. 1

Empty shells: valves separate. Part of the Grand Manan commercial catch for the winter of 1931-32. Dragged on the Duck Island beds, with commercial drags (3-inch mesh), shortly before January 29, 1932. Depth 9-10 fathoms: bottom sand and shells.

Probably these shells were taken at different times, and do not represent one community alone.

Sample No. 2

Empty shells: valves separate. Part of the Grand Manan commercial catch for the spring of 1932. Dragged in the vicinity of Duck Island, with commercial drags (3-inch mesh), during the latter part of March and early April, 1932.

It is not certain whether these shells came from the same bed as Sample 1; to judge from the shells themselves, they probably came from fairly close by.

Sample No. 3

Forty-two living scallops, of all sizes, dragged in L'Etang Harbour, N.B. with a rope drag, on August 2, 1932. Depth 5-15 fathoms. Bottom, mud and stones.

Sample No. 4

Empty shells: valves separate. Part of the Digby, N.S., commercial catch for the winter of 1931-32. Dragged off Digby with the regulation 3-inch mesh wire drags, probably during the late spring, 1932. These shells probably constitute a heterogeneous sample from many beds, inshore and offshore, and possibly more particularly the offshore snow grounds.

Sample No. 5

Empty shells: valves separate. Part of the Chester, N.S., commercial catch for the winter of 1931-32. Dragged in Mahone Bay.

Sample No. 6

Empty shells: valves separate. Part of the Mutton Bay, P.Q. commercial catch for the winter of 1932-33. Dragged about two miles west of Mutton Bay on the north shore of the St. Lawrence, in from one to four fathoms of water, during the first week in November, 1932.

Sample No. 7

Empty shells: valves separate. Part of the Gaspé, P.Q., commercial catch for the winter of 1932-33. Dragged in Gaspé Bay towards the end of 1932.

Sample No. 8

Whole scallops preserved in formaldehyde. Dragged near Carleton, P.Q., in the Baie Chaleur during the late spring of 1933. Of the sixty-six specimens in the sample, twenty consisted of shells only and the remainder contained the preserved animals in not very good condition.

Sample No. 9

One hundred convex valves, 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 north-west 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 investigation boat, "Nova IV". He reported them then as being too small for commercial exploitation; but apparently since then they have 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 No. 10

Seven scallops, all very well-marked, constituting the pick of about two dozen shells that were dredged from the Biological Board boat, "Delphine", July 27, 1934, at the inner end of Big Letite Passage, Passamaquoddy Bay. 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 indisputably significant; but since these measurements showed good correlation from shell to shell, they are included here for what they are worth.

Sample No. 11

For the sake of clarity, five samples of shells are classed together in this sample, since they all came from the same place.

These samples were obtained once a month by Captain Shirley Tidd of Digby, from 3½ miles N.N.W. of Gulliver's Head, Digby Neck, in the Bay of Fundy, on the "inshore grounds". Depth 35-40 fathoms: bottom, sandy with small rocks. The five sub-samples were taken as follows:

(a) February 20, 1935
(b) March 20, 1935
(c) April 20, 1935
(d) May 20, 1935
(e) June 14, 1935
(The day before the close season commenced)

Each sub-sample consisted of from 217 to 327 convex valves, which were kept in very excellent condition for the study of the formation of the winter rings, which was undertaken this summer (1935) in Digby.

Sample No. 12

Scallop-shells dragged throughout the summer of 1935 on the "offshore" ground--the Snow Ridge: eight miles N. Point Prim. Depth 40-45 fathoms. Bottom, sandy with a little mud.

Figure 18 indicates the localities whence the scallops in these various samples came. It will be noted that these samples of scallop shells, coming as they do from localities widely separated along the eastern coast of Canada, are representative of a great variety of conditions. Rapid currents characterize Letite Passage and the sea off Gulliver's Head: the Grand Manan scallops in general come from water that is quite shallow, whereas those from Digby are from water that is relatively deep: L'Etang Harbour scallops live in water that is quite sluggish: Carleton scallops come from the relatively warm waters of the Baie Chaleur, while it is probable that Mahone Bay, Digby and Mutton Bay scallops are all characteristic of waters that are of low temperature.

With the exception of Sample No. 3, the material examined in the study of growth consisted entirely of the upper or convex valves of the shells. A comparison was early made (in Sample 3) between the upper and lower valves for distinctness of the lines of growth, and total length. It was found that whereas the lines of growth in upper and lower valves of the same animal were equal in number whenever it was found possible to count them on both, those on the upper valves were generally found to be more clearly marked, due chiefly to the pigment rings concentric about them, which do not apparently occur in the lower valves.

It was also found that the lower valves were often worn so much by contact with the sea-bottom, that it was impossible to discern any lines of growth at all.

The average total length of the upper valves (Figure 19) was found to be about 2 m.m. greater than that of the lower valves, although in well-preserved shells whose edges had escaped being chipped, this may be reduced somewhat.

In some specimens, particularly in the Grand Manan and L'Etang samples, the upper valves were considerably riddled by the holes of the boring sponge Cliona, and inhabited either by the sponge or by some annelid forms, such as Dodecaceria; and this rendered it difficult if not impossible to discern especially the first rings. In other specimens, the rings were completely covered, particularly in the vicinity of the umbones, by coralline growths. It was made a strict rule throughout the whole investigation that all shells whose rings could not be discerned clearly and indisputably, should be rejected as a source of error in the final averages of measurements taken,

It is to be noted that all the samples enumerated above that form part of a commercial catch have probably been taken by drags with regulation 3-inch mesh; hence it is probable that most of the youngest scallops were enabled to escape, and for this reason such samples cannot be taken as representative samples of the scallop-population in the localities from which they came.

(b) Methods Used

Figure 19 shows the various methods of measurement employed. In practice, a pair of dividers were used with a ruler graduated in millimetres. The space upon the shell to be measured was marked off with the dividers, which were immediately placed upon the ruler against the millimetre scale, indicating the measurement taken. This was noted down on a form previously prepared for filling in. All scallop shells that had been measured were marked with a number, corresponding to a number on the form, in order that results might be checked if deemed necessary.

In the measurement of total length, the shell was placed directly upon the ruler, concave side down, with the umbo resting upon the scale at one end, and the opposite edge of the shell at the other. The reading at the umbo (100 m.m. for convenience) was then subtracted from the reading at the latter, giving the total length of the shell.

Weight measurements of living specimens will be discussed later.

(c) The Criterion of Growth

It is necessary that a satisfactory criterion, or basis for measurement, of growth be something that can be measured with both ease and accuracy. Three such criteria of the growth-rate of the scallop may be taken. They are: rings of growth, if deposited at regular, known intervals; length (or width); and weight. Volume and depth appear to be too variable within one sample to demand much attention in this respect.

(1) Rings of Growth:

There seems to be no doubt that the rings upon the shells of Placopecten are annual. This point is of such importance to the present investigation that it may well be said that the whole problem of growth-rate in the scallop focuses upon the establishment of the annual nature of these rings. The establishment of this fact upon a sound basis, I believe to be the most important single fact revealed in the whole investigation, and the basis for the presumption that the rings of growth are annual merits some discussion. To follow out the suggestions of Weymouth, mentioned above, it is first necessary to show that the rings are distinctive in appearance, and can be recognized by a competent observer in the great majority of cases. The clarity of these rings has already been discussed at some length in this thesis, and it only remains to refer the reader to Figure 20, which shows a typical Digby scallop shell, whose rings are revealed by transmitted light. It is true that this specimen is a good one for the purpose: but once a few good shells have been examined by a novice, there should be no difficulty at all in his recognizing the exact positions of the rings in shells on which they are somewhat less clearly defined.

To continue following out Weymouth's suggestions, it is next necessary to show that only one ring is formed each year--i.e., that the rings are annual. This can be done in two ways: by a definite seasonal relation of the rings to the forming margin of the shell, and by the agreement in number of the rings with the evidence from the modes of the age-groups.

With regard to the first method: it can be attacked either statistically or experimentally. It has been possible to do both in this study.

1. THE STATISTICAL EVIDENCE:

For this purpose, the shells of the five sub-samples in Sample No. 11 were used. From each sub-sample fifty shells were taken and examined carefully with a view to determining the relationship of the outermost ring of growth to the periphery of the shell, only those shells whose margins were entirely unchipped being used for the purpose. The results of the examination of these shells are summarized in Table IV:

TIME SAMPLE WAS TAKEN	% of shells without sign of new ring forming at edge of shell.	% of shells with new ring forming at edge of shell.	% of shells with a complete new ring formed at edge of shell
Febr. 20, 1935	64	28	8
March 20, 1935	22	48	30
April 20, 1935	8	44	48
May 20, 1935	--	10	90
June 14, 1935	--	--	100

TABLE IV. The time of appearance of the winter ring in scallops from off Gulliver's Head, Nova Scotia.

The shells in these samples were all very clearly marked as to rings, and of the above results there can be no doubt at all. It appears, then, that the ring is formed during the winter-time, about the months of

March and early April, which are just subsequent to the time of lowest temperatures (February). That the ring is not discernible in most cases during February is probably due to the fact that in order to be recognized clearly, a certain amount of subsequent shell-growth must take place, which will reveal it as distinct from the shell on either side of it.

Apparently in some specimens, the ring begins to form before February, since by February 20th, 8 per cent of the shells had already completed their rings. By May 20th, 90 per cent had completed their rings: and it is probable that before the month of May was out, the other 10 per cent had done likewise, for by June 14th, all shells had deposited their rings, which were at that time very clearly marked.

The above samples contained scallops of all sizes, bearing from 3 to 9 or 10 rings; hence it would appear that all these rings upon the shells of the scallops are annual in nature.

To be deduced from the above figures are also the following inferences:

That due to the fact that some of the rings are not deposited within at least two months of the spawning period, and also because they are present on the shell at points too close to the umbo to correspond with the size of mature scallops, they are in no way related to the spawning of the scallop. This is in very marked contrast to Pecten irradians, the Bay Scallop, in which Gutsell (16) has found that the check-mark upon the shell is closely related to the spawning act, and not to decreased metabolic rate due to the low temperature of winter-time. In Placopecten, the most rapid growth appears to take place actually during the spawning season, which is the summer, or time of highest water-temperatures.

That only one ring is deposited in a winter. In no cases was there any evidence to show that more than one ring was deposited during these months in these samples.

That the formation of the rings is probably due, as with Tivela, to slow or stopped growth from low temperatures (this may be indirectly through lack of food slowing of ciliary action in the feeding mechanism, as occurs during low temperatures with the oyster). This is strongly suggested by the actual time at which the rings are deposited, with relation to the prevailing environmental temperatures.

Figure 21 graphically indicates the above results.

The subsequent cursory examination of many shells shows beyond doubt that in the spring a ring may be expected at the periphery of all shells: and that as the summer progresses, the amount of new shell gradually increases until the ensuing winter, when growth slows up again and another ring is formed with the resumption of growth the following spring. There can be no other way of explaining these results than that the rings are annual.

One more statistical example may be cited in support of the theory. The ring-frequencies of the five sub-samples of Sample 11 were taken, and reveal the interesting fact that whereas the February Sample (11a) was characterized by a predominant age-group possessing five rings on its shells, the June Sample (11e) was characterized by the almost complete absence of such five-ringed shells, and by the great predominance of a group possessing six rings. An examination of the ring-frequencies of the intervening Samples (11b - 11d) reveals the fact that it is the five-ring group that has become, during the course of the spring, the six-ring group. The data upon this aspect of the question are presented in Table V and Figure 22.

NUMBER OF COMPLETE RINGS	SAMPLE 11a Feb. 1935	11b Mar. 1935	11c Apr. 1935	11d May 1935	11e June 1935
1	---	---	---	---	---
2	1	1	---	---	---
3	19	11	3	9	2
4	10	24	11	67	22
5	76	66	57	24	10
6	34	33	57	69	139
7	8	3	5	9	5
8	7	6	9	2	---
9	11	6	6	4	---
10	4	11	7	3	1
11	---	4	7	4	2
12	---	1	---	5	4
13	---	---	---	9	3
14	---	---	---	1	4
No. of Shells Examined:	170	166	162	206	192

TABLE V. Ring-frequencies in Sample 11, from 3½ miles N.N.W. Gulliver's Head, Nova Scotia.

2. THE EXPERIMENTAL EVIDENCE:

This is based upon an experiment that was run at the St. Andrews Biological Station during the winter of 1934-35. A strong box was constructed with a double wall of wire netting at either end to allow of the free passage of water through it when submerged; and in it were placed, on a floor of gravel, 38 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, 1934, in about five fathoms for the winter ensuing, to be examined in the spring after (presumably) the scallops had deposited their "annual" ring. On June 14th, 1935, the box was re-examined. It had been undisturbed for nine and a half months, during which the low-temperature period of the year (February and March) came a little over two-thirds of the way from the beginning to the end of the experiment.

Of the thirty-eight scallops that were originally placed in the box, eighteen survived, the others having died, to judge from the great amount of variation in the quantity of shell deposited subsequent to the nick-mark, at different times throughout the winter.

It is not only interesting, but highly significant to note that seventeen of the eighteen living animals had deposited a very definite ring, similar in every respect to the growth-rings on the previously deposited portions of the shell; and that in the majority of cases this ring was roughly two-thirds of the distance from the nick-mark to the periphery of the newly-formed shell. The eighteenth shell, which showed no ring mark, was a very old one, possessing upwards of ten rings on its shell; and it had not apparently deposited any new shell at all during the experiment. It is therefore believed that the single exception should in no way interfere with the obvious inferences to be derived from the results of the measurements of the other seventeen shells.

In all cases where growth was recorded in these experimental shells, the shock of capture, handling and filing the nick-mark upon the shell was recorded as a very abrupt check-mark extending all the way around what was, in September, 1934, the periphery of the shell. This must necessarily be disregarded in the examination of the shells, insofar as it merely signified an unnatural temporary cessation of growth that in a short time was apparently resumed in a normal manner. Subsequent to this check-mark, a considerable amount, particularly in the younger specimens, of new shell without any check-marks was laid down. This was followed by the deposition of the ring-mark, which in some of the specimens was very clearly defined due to the presence of a pigment ring; and subsequent to the ring occurred another more or less extensive area of smooth shell. It seems, then, that the layer of shell next to the check-mark corresponded to the period of growth in the autumn, when the water-temperature was still fairly high: that the ring corresponded to the period of lowest temperatures in the early spring, when growth practically stopped: and that the outermost layer of clear shell corresponded to the more or less short period of growth during the spring promoted by the rising temperatures. In any case, the fact that these scallops deposited a definite ring in virtually all cases, coupled with the statistical evidence quoted above upon the Gulliver's Head shells, leaves little room for doubt that these rings of growth are annual, that they are deposited but once a year, and that they are deposited upon the shells in the winter-time, probably at that time when the water-temperatures are at their minimum.

Figure 24 consists of two photographs of some of these shells, showing nick-marks, the added shell, and the new ring about two-thirds of the way across it.

Table VI consists of the measurements obtained from each of the seventeen shells, and Figure 25 graphically presents the data in this table.

Length of scallop:umbo to nick-mark	Width of penultimate ring-space	Width of ultimate ring-space	Nick to added ring	Added ring to periphery	Total added shell
79.4	25.0	13.4	4.3	2.0	6.3
95.5	17.7	11.5	3.0	1.8	4.8
80.0	25.9	17.8	5.4	5.2	10.6
104.0	23.6	18.5	3.4	2.5	5.9
107.0	22.9	11.0	3.7	2.0	5.7
106.1	15.0	11.4	2.0	1.8	3.8
84.9	18.5	15.6	6.5	3.7	10.2
85.9	25.4	26.0	10.2	3.6	13.8
84.3	31.6	17.9	4.7	2.0	6.7
83.6	29.7	15.3	5.0	5.7	10.7
101.4	20.6	9.9	4.7	2.1	6.8
108.5	18.3	6.1	3.4	2.0	5.4
121.0	11.3	4.5	2.0	1.0	3.0
125.9	9.7	3.2	2.5	1.0	3.5
130.8	11.6	3.4	2.4	0.9	3.3
130.8	7.4	2.4	2.1	0.5	2.6
140.9	8.4	5.4	2.4	1.3	3.7

TABLE VI. Measurements showing the amounts of shell added to the periphery of experimental scallops at St. Andrews, during the winter of 1934-35. All measurements in millimetres.

Thus both statistical and experimental evidence has been presented in support of the theory that the rings upon the shells of Placopecten are annual: and in the light of this evidence it will be henceforth assumed in this thesis that this is so.

In order that these rings may be taken as a criterion of growth-rate, it is also necessary to show, continuing with Weymouth's hypothesis, that the number of rings upon the shells agrees with the evidence from the modes of the age-groups. In other words, it stands to reason that if the rings are to be taken as a criterion of growth-rate, the dominant age-group in any sample, when measured for length, weight, or any other suitable proportion, will also form the dominant age-group in the sample when measured for the number of rings. Two examples, constituting comparatively large samples of scallop shells characterized by the predominance of one particular age-group will suffice for the purpose: Sample 1 and 11e, from Grand Manan and off Gulliver's Head respectively. Table VII and Figure 26 summarize the data.

SAMPLE #1		SAMPLE #11e			SAMPLE #1		SAMPLE #11e	
Lengths	Frequencies	Lengths	Frequencies	No. of Rings	Frequencies	Corresponding Length	Frequencies	Corresponding Length
76- 80	1							
81- 85	16	81- 90	5	1	--		--	19.4
86- 90	64			2	--		--	54.3
91- 95	182	91-100	20	3	--	70	2	81.9
96-100	180			4	13	83	22	101.3
101-105	100	101-110	29	5	78	100	10	114.4
106-110	17			6	5	114	139	124.1
111-115	1	111-120	98	7	3	123	5	131.2
116-120	1			8	2	130	--	136.9
121-125	3	121-130	74	9	5	135	--	141.4
126-130	5			10	2	141	1	145.2
131-135	15	131-140	17	11	1	145	2	148.3
136-140	16			12	--		4	
141-145	9	141-150	5	13	--		3	
146-150	6			14	--		4	
151-155	1							
TOTALS:	618	--	248	--	109	--	192	--

TABLE VII. Length- and Ring-frequencies in Samples 1 and 11e, together with lengths of shells corresponding to the number of rings, as determined by measurements of ring--widths, and averaging these for many shells from each of the two localities represented.

It seems quite clear from the results of both these examples that the number of rings upon the shells agrees very closely with the evidence from the length-frequencies of the same samples. The apparent lag of the predominant mode in the ring-frequency curve of Sample 11e behind the corresponding length-frequency mode is explained by the fact that in these shells, the sixth ring had only very recently been formed, and the length corresponding to six rings (as determined by the averages taken from but one age-group in Sample 11e, an age-group exhibiting exceptionally high growth-rate) would not differ very much from that corresponding to a little over five rings.

For these reasons, then, I consider it justifiable to regard the rings of Placopecten shells as criteria of the growth-rate: and as such they will be considered henceforth in this report.

(ii) Length:

Length and width might both be measured conveniently; however, length has been chosen as the more satisfactory proportion for quantitative measurements, since the liability to error from chipping is reduced to half that of width. In length measurements, only one edge of the shell is involved--the edge opposite the umbo; and the umbo is generally quite solid enough to resist much force. In width measurements, on the other hand, two edges that are easily chipped and liable to prove a source of error, are involved.

Length has been used as a criterion of growth very widely. It is applicable to such animals as scallops, which are known to increase in length with age: and has been used in the present investigation with regard to (i) ratios involving the total size of scallops, and (ii) the total addition per ring of growth in length of the shells.

(iii) Weight:

This is a very important factor in the study of growth in animals, and is useful as a criterion of growth particularly with such forms as cannot well be measured in any other way for increase in size. The significance of measurements of weight lies in the fact that they form a true index, as do measurements of volume, of the actual increase in growth: whereas linear measurements such as length only give us a general idea of the increase in one dimension.

Only Sample No. 3 furnished material for the study of weight relationships in Placopecten; and since this Sample was not very large, only a general idea of them has been obtained. However, for the actual purposes of this investigation, weight is not so important as are length and a study of the rings of growth.

(d) Number of Growth-Rings

It follows naturally from the argument showing the annual nature of the rings that since the space upon the shell between two rings represents a year's growth, the number of spaces, which equals the number of rings if the shell outside the ultimate ring is excluded, upon a scallop's shell represents its age in years. An estimate can therefore be made of the maximum age to which scallops grow in any region, by selecting the shells with the greatest number of rings from large samples, and noting this number. Such maxima were determined for the following localities as follows:

Chester, Nova Scotia	15	L'Etang, N.B.	13
Digby, Nova Scotia	15	Gaspé, P.Q.	13
Grand Manan, N.B.	12	Mutton Bay, P.Q.	15
		Carleton, P.Q.	13

Figures are not given for other places whence samples have been received since in some cases the samples were too small for the determination of a significant maximum; while in other cases, such as the scallops obtained from the Wolves, N.B., practically all the shells were obviously very young, and would grow considerably older if left undisturbed.

It appears, then, that scallops will attain an age of fifteen years under suitable conditions: and I believe, to judge from the apparently healthy nature of some of these old shells, particularly those from Chester and from the inshore waters off Digby, that this maximum is very probably exceeded. Furthermore, it is probable that the relatively low maxima recorded for Grand Manan, L'Etang and Gaspé are not truly representative. If large enough samples were examined, it is believed that older shells than these would be forthcoming.

It should perhaps be stated here that, in most cases, old shells such as these contain scallops that are very poorly meated. The adductor muscle is small, watery, dark in colour and easily detached from the muscle scar on the shell. Such scallops are known to the fishermen as "Nigger Scallops", and I am told that when scalloping is going on over the Snow Grounds, vast quantities of these old scallops are half shocked and thrown overboard as worthless. Since it is probable that these older scallops produce very large quantities of eggs and sperm in comparison to younger ones, it seems that this must be a very great and destructive wastage.

The age to which Placopecten grows in Canadian waters is in marked contrast to the age to which the small southern Bay Scallop (Pecten irradians) grows. The latter seldom lives more than two years, and very often only twenty months.

(e) Growth in Length

(i) The Age-Group Determination of Growth-Rate:

Unfortunately, until quite recently it has not been found possible to obtain regular samples of scallops from one particular area over a long enough time to reveal the progress of the modes of age-groups in length-frequency polygons. In the present year, however (1935), such a series of regular samples has been commenced (Samples 11a to 11e). Thus far five have been received, each a month from the preceding one, covering the months February to June. It is proposed to keep up these samples for at least one whole year. The months from February to June effectively cover the low-temperature period of the year, and as has been pointed out already, this is the time at which growth is slowest in the scallops. It would therefore be expected that in the series of frequency polygons corresponding to these five samples not very much progress in age-group modes would be apparent. Such is found to be the case (Figure 27). In these samples, the predominant age-group is one characterized by the possession of five rings (latterly six), and of an average length of approximately 117 millimetres. There is not much difference in the position of the February mode and the June one for this group, showing that practically no growth had taken place in these months. However, this is not strictly true, since although the amount of growth was insufficient to remove the mode from the 110 - 119 m.m. category into the 120 - 129 m.m. one, a certain amount of growth actually did take place. This has been shown by a more analytical examination of individual shells. It is expected that subsequent samples during the summer period of rapid growth will show a very definite shifting of this mode.

Table VIII gives the actual values of these length-frequencies.

Length Categories	SAMPLE 11a Feb., 1935	11b Mar., 1935	11c Apr., 1935	11d May, 1935	11e June, 1935
60-69 m.m.	--	--	--	--	--
70-79 "	--	--	--	1	--
80-89 "	3	4	1	19	5
90-99 "	18	28	13	70	20
100-109 "	20	25	13	40	29
110-119 "	89	102	94	93	98
120-129 "	66	59	60	54	74
130-139 "	13	28	31	34	17
140-149 "	10	11	4	15	5
150-159 "	1	1	1	--	--
160-169 "	--	--	--	--	--
TOTALS:	220	258	217	326	248

TABLE VIII. Length-frequencies of the five samples, 11a, 11b, 11c, 11d and 11e, from 3½ miles N.N.W. Gulliver's Head, Nova Scotia.

(ii) Total Lengths of Scallops at the Times of Deposition of the Rings of Growth:

In the measurement of the rings of growth, rings beyond the ninth were, in most cases, not considered because in a large number of specimens they were found to be somewhat too indistinct and narrow for accurate measurement. For the purpose of obtaining a general idea of the comparative growth-rate of the scallops from scattered points along the eastern coast of Canada, Samples 2 - 10 were used, since each of these samples contained a number of age-groups, which fact made it possible by averaging the results of measurements, to obtain a general estimate of the growth-rate in any one area. That this is not a true method of comparison, however, will be seen later. It is necessary, in order to make a true comparison, to use not general samples, but particular age-groups for comparison. However, there are certain advantages in the more general method, particularly from the commercial point of view: for in such a way a fairly ready estimate can be made, applicable at all times in the particular region for which it has been calculated, not only of the growth-rate but also of the approximate time it takes for scallops to attain the legal size of four inches.

Measurement was made around the shells from the umbone along the median line of the shell to each ring. Figure 28 shows the resulting curves for the nine localities considered, and the average curve for the whole.

For Table IX see next page.

LOCALITY	1st Ring	2nd Ring	3rd Ring	4th Ring	5th Ring	6th Ring	7th Ring	8th Ring	9th Ring	Number 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
Gaspé, P.Q.	16.6	40.2	62.8	78.9	91.2	101.3	110.2	119.9	127.8	100
Digby, N.S. Sample 4	23.2	50.7	76.4	95.5	106.9	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
Letite Passage N.B.	19.8	50.8	80.0	101.5	118.4	130.5	142.5	152.4	159.3	7
AVERAGES for WHOLE:	18.9	44.95	70.8	90.5	105.1	116.1	124.9	132.5	138.1	909

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

These curves are of double significance. They indicate the lengths of the scallops in different regions at the times the rings were deposited upon the shells, showing clearly how growth is retarded as the molluscs become older; and they also show the age at which the scallops attain the legal size of four inches (100 m.m.) in these different areas. It will at once be noticed that there is considerable variation in the positions of these curves. L'Etang scallops form one extreme, in which the growth is apparently very slow, but in which the slow growth persists at an approximately uniform rate after scallops from the other localities have begun to decrease the speed of their growth. The general sample (no. 4) of scallops from Digby appeared very closely to approximate the average in its rate of increase, but there is ample reason to suppose that there is considerable variation in the growth-rate of scallops from the Digby area and that this sample probably showed a growth-rate rather under the typical rate for Digby. Both Mahone Bay and Grand Manan scallops appear to grow very fast: and this applies also to the shells in the small sample obtained from Letite Passage. The Grand Manan scallops apparently increase their length faster than the others up to the time of deposition of the fourth ring (4th year). After that, their rate of growth diminishes, and the Mahone Bay scallops take their place. Thus in scallops from these regions, possessing over four rings upon their shells, the largest may be expected to have come from Mahone Bay. However, some Digby scallops (to be discussed later) grow considerably faster at certain periods of their lives than the scallops from Mahone Bay.

Since the rings of growth are annually deposited, a very significant comparison may be drawn between these curves. A vertical line from the 100 m.m. point on the abcissa has been drawn intersecting the growth-curves. The points on the ordinate corresponding to these points of intersection will therefore indicate the number of years that had passed up to the time the scallop attained the legal size of four inches. It will thus be seen that the L'Etang scallops took six years, whereas Mahone Bay and Letite scallops took less than four years to attain this size. The other regions apparently came between these two extremes in this respect. Certain scallops in Sample 11 (to be discussed later) took barely three years to attain the legal size, this constituting the extreme minimum recorded during the investigation.

These facts are of vital significance in the conservation of the scallop-beds for the future of the fishery. From this it can well be seen how important a bearing the establishment of the annual nature of the rings has upon the fishery. If it is known for certain how much time elapses before a young scallop attains the legal size, conservation methods can be applied for a predetermined definite period of time, sufficient to cover the growth requirements of the scallops, with reasonable prospect of success.

It should be indicated here that the curves in Figure 28 are not the actual growth-curves of the scallops, since they do not take into account the fluctuations in growth-rate at different times in each year. They may therefore be termed "aggregate" growth-curves, since they only indicate the aggregate amounts of growth per yearly period. The actual growth-curve, and fluctuations occurring in it, will be discussed later under "Growth in Relation to Environment". (Figures 29 & 30)

(iii) Growth of Scallops per Added Increment:

Perhaps a more graphic and precise method of comparing the actual aggregate rate of growth of Placopecten in the regions under discussion is shown in Figure 26, which indicates the average additions in length to the shells of the scallops, per year's growth. Very marked differences can be observed in these curves, which are plotted, as in Figure 28, for Sample 2 - 10. In general, the greatest amount of growth takes place during the second and third years. In L'Etang, Carleton and Mutton Bay scallops, the peak was attained during the third year. In all the others, it was attained during the second. The latter appears to be the more typical case, although in many scallops the growth during the second and third years is approximately equal. It must be remembered that the figures for these curves (Table X) are but means, and do not express in any way the actual variation among scallops in one sample. This explains the relatively low value obtained as the mean of the measurements of the first ring, with relation to the second and third. The maximum measurements obtained for the first ring lead us to believe that if a scallop settles as spat early during the course of its first summer, it may grow during that summer nearly as much as during either of the two subsequent summers. The fact, however, that the height of the spawning season occurs during July and August, about half-way through the summer, leaves only the latter half of the summer available as a period of growth for the spat; and this, applying as it does to the majority, explains the relatively low value obtained above for the first ring. This will be discussed in more detail subsequently. In all cases the additions in length during the first three years much exceeded the additions in length during any subsequent years. This retardation of the growth-rate is very clearly shown in Figure 31. As in Figure 29, it can be seen that L'Etang scallops came nearest to constant growth-rate, whereas Grand Manan ones varied most widely from it. Mahone Bay scallops, however, presented an example of high growth-rate well-sustained. Scallops from the remaining localities came intermediate between the two extremes.

In general, it may be said that scallops show a very typical animal type of growth-rate. Its great rapidity during the earlier stages may be ascribed to the more active metabolism characteristic of all young animals. After the deposition of the fourth ring, growth is far less active, and considerably more uniform than previously. This is more or less characteristic of any adult animal, in that before maturity is attained, most of the animals' energies are utilized in growth processes; whereas once the gonads become mature, the animals' energies are largely concerned with production of the genital products, to the sacrifice of the growth in size of the whole. It is probable, then, that the period of growth extending up to the time of deposition of, roughly, the fourth ring corresponds to the immature and adolescent stages; and the period subsequent to the adult life of the scallops. Scallops off Digby do, however, spawn during their fourth summer, and occasionally during their third.

LOCALITY	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	Number of 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	31.4	30.3	17.1	12.6	9.5	7.8	6.1	4.4	200
L'Etang N.B.	16.4	18.5	[illegible]	17.3	14.6	13.4	11.5	9.2	7.0	42
Carleton P.Q.	16.1	21.5	23.7	19.9	14.3	10.4	7.9	5.6	4.25	59
Gaspe P.Q.	16.8	23.4	27.3	16.1	12.5	10.1	8.9	9.7	7.9	100
Digby, N.S. (Sample 4)	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
Letite Passage, N.B.	19.8	31.0	29.2	21.5	16.9	12.1	12.0	9.9	6.9	7
AVERAGES for WHOLE	18.9	26.0	25.8	19.[illegible]	14.6	11.0	9.0	7.3	5.7	909

TABLE X. Average additions in lengths of scallop shells from different localities per year of growth. Upper valves. Measurements in millimetres.

(iv) Length-Width Relationship:

This is the first of a number of ratios between length and other proportions that will be considered in this report, chiefly for the purpose of defining more accurately the proportions of the scallops, since such ratios are of little other than scientific value.

The relation between total length and total width of Placopecten shells was found to be very constant for all the areas considered. Taking the L'Etang sample as a typical example (Sample No. 3), the following values were obtained (Figure 32):

Length m.m.	Width m.m.	Length m.m.	Width m.m.
52.5	49.5	103	106
52.5	49.5	103	102
75	71	110	116
88	91	114	116
89	89	123	123
96	99	132	132
96	98	146	154
		157	166

The curve in Figure 32 is almost linear. In general it may be said that, as the scallops become older, their width very slightly exceeds their length. This is particularly so with the Mahone Bay Sample (No.5), where the width often quite considerably exceeded the length. Figure 33 is a reproduction of two outlines of scallop shells superimposed, one from Grand Manan, the other from Chester (Mahone Bay), both of equal length, indicating this characteristic. Otherwise length and width are approximately equal. The curves for all the other regions so closely approximate that of the L'Etang specimens, that it is considered sufficient to use only these as an example.

(v) Length-Depth Relationship:

Since measurements to determine this ratio could only be made upon whole scallop-shells with both valves joined, they were confined to Sample No. 3, which consisted of living scallops. The total lengths (umbo to opposite edge) and depths (greatest perpendicular distance, when the shell is closed, from the exterior of the upper to the exterior of the lower valve) of all the 42 scallops in the sample were recorded, and a curve plotted (Figure 34). The following is a representative series of the measurements taken:

Length m.m.		Depth m.m.	Length m.m.		Depth m.m.
52.5	....	15	106	....	32
52.5	....	13	110	....	32
75	....	22	113	....	35
79	....	27	113	....	35
85	....	23	118	....	38
88	....	26	123	....	40
93	....	27	128	....	37
94	....	26	132	....	32
94.5	....	26	137	....	40
103	....	32	146	....	46
			159	....	52

Considerable variation from the mean was found. For example, two specimens of a depth of 32 m.m. were respectively 103 and 132 m.m. in length. In general, it may be said that although there was an increase in depth as the L'Etang scallops increased in length, there was no close correlation between length and depth.

It is probable that this applies almost equally well to scallops from all the areas under consideration.

(vii) Length-Hinge-Line Relationship:

A means of comparison, more of systematic than commercial interest, was found in an examination of the relative lengths of the hinge of scallops of given total lengths from different areas. It was noted that scallop-shells from some places appeared to possess a much broader hinge line than scallops from others. To illustrate this graphically, the total lengths of scallops from Mahone Bay, Digby (Sample No. 4), and Grand Manan were plotted against the lengths of their hinge-lines, the resulting curves being shown in Figure 35. Table XI gives representative measurements for the three localities.

GRAND MANAN, N.B.		DIGBY, N.S.		MAHONE BAY, N.S.	
Length	Hinge Line	Length	Hinge Line	Length	Hinge Line
80	34	79	36	106	46
85	33	83	36	110	60
86	35	85	37	117	54
86	39	95	41	118	61
90	37	98	46	121	54
93	39	100	41	121	61
94	41	120	49	126	68
99	42	123	55	130	66
100	44	124	52	131	68
102	42	125	54	136	76
109	44	126	62	136	70
118	47	126	55	136	74
127	57	126	58	143	61
131	58	127	52	143	62
131	58	129	54	144	79
137	66	131	57	145	70
138	59	134	58	145	76
141	54	143	63	145	73
143	58	146	61	150	79
MEANS:	46.68	---	50.9	---	66.21
P.E. of MEAN:	±6.7	---	±5.9	---	±6.0

TABLE XI. Length and Hinge-Line relationships in scallop shells from Grand Manan (Sample 2), Digby (Sample 4), and Mahone Bay (Sample 5). Upper valves. Measurements in millimetres.

It can be seen from these curves that in the Mahone Bay scallops the hinge-lines are on the average proportionately much wider than in the other samples. That this difference is a significant one is shown by the probable errors of the means that are included in Table XI. Reference again to Figure 33 clearly shows this characteristic. The great difference in the length of the hinge-line in the two scallops figured is quite apparent. It is impossible to say at the present time to what factors or set of factors such a difference could be attributed.

(f) Growth in Weight

Since Sample No. 3 consisted of living scallops, it formed the basis of the weight measurements that were taken. This sample was composed of only 42 animals, hence too general conclusions cannot accurately be drawn until further observations have been made. However, the sample was sufficient to provide a general idea of the proportion ratios involving the factor of weight.

In weighing the scallops alive, it was essential first to remove all the water from their shells. Dessication is perhaps the most efficient method of doing so; but it presented many difficulties due to the relatively large size of the scallops, and to the time it would take to accomplish thoroughly. For roughly comparative purposes, as in the present case, it was considered sufficient to hang the scallops umbo uppermost until they ceased dripping. The shape of their shells, and the arrangement of the viscera within them, made it possible for a very large percentage of the water to drip out. The specimens were then weighed upon a torsion balance to the nearest gram.

(i) Weight-Length Relationship:

Weight, as obtained by the above method, was plotted against length in the L'Etang scallops; and Figure 36 shows the resulting approximate curve obtained from the measurements taken. As in the length-depth curve, considerable variation from the mean was found, increasing with the age of the scallops. In this case, it is possible that this was largely due to experimental error (varying quantities of water in the shells); but this cannot be the sole cause. In general, it is seen that increase in weight is very rapid in proportion to the length after a total weight of about 80 grams has been attained. This is typical weight-length curve, and is found in similar form in very many groups of animals. The following figures are representative of the sample:

Length m.m.	Weight, grams	Length m.m.	Weight, grams
52.5	18	115	222
52.5	20	119	290
75	68	123	228
87	114	127	351
88	108	128	300
89	107	135	472
96	125	136	379
96	127	137	322
103	164	139	376
109	281	146	441
110	212	147	440
110	183	154	525
114	205	157	470

(ii) Weight-Ring-Number Relationship:

Weight was also plotted against the number of ring-spaces upon the scallop shells in Sample No. 3, thus giving a general estimate of the weight L'Etang scallops attain in a given number of years. The resultant curve was very similar to that in Figure 36, except that there was a suggestion of retardation in the weight increase after the deposition of the ninth ring. Growth at this stage appears to be slowest in the scallops, and such retardation is to be expected. The variation from the mean is very great in some specimens. There is, however, a definite correlation, as should be expected, indicated by the similarity in the direction of the curve and that of the line representing a perfect correlation (Figure 37). The following figures indicating the weight relationship to the number of rings form a representative series from the sample:

No. of Ring-spaces (years)	Weight, Grams	No. of Ring-spaces (=years)	Weight, Grams
4	18	8	228
4	20	8	195
5	87	8	286
5	127	9	237
6	107	9	291
6	108	9	287
6	114	9	237
6	125	10	322
7	120	10	278
7	122	10	290
8	212	10	300

From the discussion upon weight relationships, and from an examination of the examples cited, it appears that, due to the wide variation that occurs, weight cannot be used with much success as a criterion of growth in L'Etang scallops. All the specimens in Sample No. 3 were taken within a radius of about half a mile, and there is no reason to suppose that the individuals constituting this sample had migrated to L'Etang Harbour from a number of different regions in which varying conditions, which might possible have accounted for the above variations in the scallops, obtained. L'Etang Harbour is a comparatively secluded inlet of the sea, and it is reasonable to suppose that these scallops had spent their whole lives there--a supposition strongly supported by their apparently characteristically slow growth (Figures 28 and 31). If this be so, the apparent variations in weight occurred under more or less identical conditions: and if under approximately identical conditions the weights of two scallops do not increase more or less alike (subject, of course, to hereditary variation), it stands to reason that weight cannot satisfactorily be taken as a criterion of growth. Forty-two specimens is, however, too small a sample upon which to base general conclusions: and it is necessary to examine more material if this is intended. In the present report, weight is not accorded much importance as a criterion of growth, since the presence of the annual rings performs the same function considerably more conveniently.

(g) The Growth-Rate in Relation to Environment

This will be simply a summary of the known data, and an attempt to arrive at some reasonable conclusions that may form a satisfactory basis for further work.

In general, the nature of the growth in animals is the result of two primary factors: heredity; i.e., the tendency of all animals to remain alike from generation to generation; and variation, the tendency to differ, which opposes heredity. In this report we are not concerned with heredity or genetic factors so much as with variation and the influence of environmental factors, in determining the welfare and course of life of the animals. Environmental factors acting upon animals of identical genetic lineage influence their mode of life very pronouncedly, and sometimes very slight changes in the environment will result in surprisingly marked changes in the animals that are exposed to them. The environment is an exceedingly difficult thing to measure on account of its extreme complexity. Not only is it composed of an enormous number of different factors, each of which has its own particular type of influence upon animals and plants: but these factors interact with one another, and thus influence the mode of life of living organisms in what is virtually an infinity of other ways. The science of ecology has, however, summarized all these factors under three main headings: chemical, physical and biotic.

The great variation that exists, as we have seen, among the scallops of eastern Canada cannot be ascribed to genetic factors alone: and there is ample reason to believe that the environment plays the most important role in determining the lives, the mortality, the success or failure of spawning, and (this is the point that concerns us) the growth-rate of the molluscs.

The steps in a discussion, therefore, upon the growth-rate in relation to environmental conditions are quite definite. A variation from the norm in growth-rate results, in the first place, in a corresponding difference in the sizes of the normal and variant individuals; and this can be easily determined by measuring the actual sizes of the two individuals. In this report we have chosen length as the most suitable criterion of growth. The next step is to show, by such measurements, that variations do occur. This has already been done in the comparison of the growth-rates of Samples 1 to 10; but it is necessary to consider the question more analytically if significant comparisons are to be drawn. Once the existence of variations has been demonstrated, it is next necessary to correlate the variations with the environmental conditions that existed at the times at which they occurred. When correlation has been shown and found to be significant, the final proof must be provided by actual experiment.

The conditions under which variations are found to occur in Fundy scallops fall naturally into three categories: (1) in the same age-group in the same locality; (2) in the same age-group in different localities; and (3) in different age-groups in the same locality. (1) would furnish us with a picture of such genetic variations as exist in any one population of scallops with, perhaps, slight modifications due to small local variations in the environment. (2) which is of perhaps the greatest importance, would give us a picture of the variation that exists between two definitely separate populations, and is probably due chiefly to actual differences existing between the environments of the places. If the various places are not geographically distant, the chances of similarity in the gross annual cycle of environmental factors would be increased. In this way, certain factors (e.g., solar radiation, temperature, etc.) could be largely eliminated in searching for the significant factors that determine the variations found. Those factors which are chiefly determined by the annual cycle of weather would be much the same in the different localities under consideration. (3) would furnish a picture of the growth-rate from year to year, indicating the variations that are principally due to differences in the yearly cycle.

To show that all three of these variation types occur among the scallops of the Bay of Fundy, we shall take each category in turn; and afterwards attempt to correlate these variations with the various individual environmental factors, or groups of the latter.

(1) Same age-group: same place.

Two age-groups of scallops taken from Sample 11 (from three miles

N.N.W. of Gulliver's Head) were used. It can be clearly seen that general samples consisting of many age-groups would be useless in this respect, since the variations occurring would be heterogeneous, and due perhaps to several sets of factors, whereas if age-groups are considered separately, it is possible to obtain a clear picture of the variations occurring under one set of conditions only--those under which the age-group as a unit of the community was reared.

Table XII and Figure 38 show the results of measuring the width-frequencies of the ring-spaces of these two groups (4- and 6-year olds),

Millimetres	1st Ring	2nd Ring	3rd Ring	4th Ring	5th Ring	6th Ring	
0-4.9	--	--	--	--	--	2	
5-9.9	1	--	--	--	71	93	
10-14.9	9	--	--	23	29	5	
15-19.9	17	--	3	65	--	--	
20-24.9	28	--	28	11	--	--	6-year group
25-29.9	30	--	55	1	--	--	
30-34.9	13	5	13	--	--	--	
35-39.9	1	12	1	--	--	--	
40-44.9	1	40	--	--	--	--	
45-49.9	--	38	--	--	--	--	
50-54.9	--	5	--	--	--	--	
0-4.9	--	--	--	--			
5-9.9	2	--	--	--			
10-14.9	10	--	--	4			
15-19.9	20	--	--	52			
20-24.9	44	--	42	42			4-year group
25-29.9	16	--	56	2			
30-34.9	8	32	2	--			
35-39.9	--	50	--	--			
40-44.9	--	16	--	--			
45-49.9	--	2	--	--			
50-54.9	--	--	--	--			

TABLE XII. Showing frequency distribution of aggregate growth-rate per yearly period in two age-groups of scallops from off Gulliver's Head, N.S. Figures represent percentages of each age-group.

These figures show several interesting points. The first of these is that considerable variation appears to occur in the width of any one particular ring-space in the one age-group. Possibly this variation is inherited: but it may also be, as mentioned above, due to slight local differences in environment. The fact that all these scallops were taken from the same place does not necessarily mean that they had lived in this place together all their lives: but the relative distribution of the frequencies in the ring-spaces subsequent to the first strongly supports this view, since these frequencies are for the most part clustered within relatively narrow limits. This would not have been expected if the scallops had been widely separated, owing to the relatively great local differentiation that exists in growth-rate. The second point to be noted is that, with successive years of growth, the distribution of these frequencies on the abcissae becomes more and more confined. It has already been shown that with age the growth-rate declines very considerably; and this means that, as the scallops grow older, they have less and less scope for variation. We should thus expect the spread of frequencies would be greatest when the scallop is young and can grow fastest. This is clearly shown to be the case in Figure 38. The third point to be noted is the extreme spread of the frequencies in the width of the first ring-space. This was possibly due in part to the above-mentioned greater scope for variation in the young individuals, but a far more probable explanation can be sought in the relation between the time at which the scallops were spawned, and the length of the particular growing-period. The spawning season extends from about the end of May to the middle of September, and the growing period probably from April to mid-November. A scallop spawned in May, therefore, has the expectancy of about five months of growth before it lays down its first ring, whereas one spawned in September has the expectancy of only about two, at the most. There would thus be expected a graduation in size of scallops at the end of their first summer's growth ranging between these two extremes: and the frequencies of the different sizes would indicate roughly the relative activity of the spawning process among the scallops throughout the summer. Thus, in both the age-groups graphically analysed in Figure 38, it can be seen that the mode of the frequency curve for the first ring-space comes more or less in the centre of its polygon, which would seem to indicate that the spawning activity of the scallops in that particular locality was greatest at about the middle, or a little after the middle, of the growing period; e.g. August.

(2) Same age-group: different places.

To avoid the possibility of error in drawing conclusions from the analyses of inadequately long series, a series of samples of scallops was obtained from four stations extending outwards from the Nova Scotia coast into the Bay of Fundy. These stations were situated respectively in the Annapolis Basin, three miles N.N.W. Gulliver's Head, on the Snow Ground, and twelve miles N. Point Prim.

Again, to obtain strictly comparable figures, as many shells as possible of one particular age-group were obtained (6-year olds) and measured. At the same time, a general estimate of the growth-rate for all age-groups was obtained for the four localities by averaging the means of each different age-group from 3 to 11 years old; and it is believed that this also furnishes a satisfactory comparative series. Both series are shown in Table XIII and Figure 39.

LOCALITY (Station No.)	1st Ring	2nd Ring	3rd Ring	4th Ring	5th Ring	6th Ring	7th Ring	8th Ring	9th Ring	10th Ring	11th Ring	No. Exam'd
A.6-year-olds	25.5	44.1	26.7	20.6	11.5	8.5	----	----	----	----	----	6
General Means	22.0	42.4	29.5	20.9	13.1	9.8	6.7	5.7	4.5	3.5	3.1	29
2.6-year-olds	23.6	43.6	26.6	16.8	9.3	7.6	----	----	----	----	----	100
General Means	19.4	34.9	27.6	19.4	13.1	9.7	7.1	5.7	4.5	3.8	3.1	260
3.6-year-olds	20.0	36.2	26.1	18.6	10.4	6.9	----	----	----	----	----	42
General Means	18.7	32.8	26.0	19.4	12.8	9.1	7.0	5.6	4.9	4.3	3.5	143
5.6-year-olds	20.2	31.4	21.4	17.1	9.9	6.8	----	----	----	----	----	33
General Means	16.2	26.8	22.2	17.2	12.2	8.7	6.7	5.1	4.1	3.5	3.1	139

TABLE XIII

Mean aggregate growth per yearly period in 6-year-old scallops (spawned summer 1928), and mean aggregate growth for all age-groups from 3 to 11 years old, from the Digby area. Figures represent mean widths of ring-spaces in millimetres.

The two sets of curves have several points in common, as might be expected. In both, the second season's growth for all four stations was greatest; and subsequent to this, the four curves in both cases tend to bunch together very closely. The significance of this, together with the great differences existing in the second year's growth, cannot be overestimated. This indicates that it is virtually the second-year's growth, helped somewhat by that of the first and third, that is the determining factor in the ultimate size differences between the adult scallops, and hence in the speed at which the scallops from each locality attain the legal size of four inches. To be noted next is the fact that, even though the curves bunch together after the third ring has been deposited, the growth in the second year for these four places forms a graded series extending from the Annapolis Basin, where growth is fastest, to the outermost station, where it is slowest. Thus the shallow-water scallops grow considerable faster in their determinative years of growth than the deep-water ones. Figure 29, a photograph of four six-year-old scallops from the four places, shows these differences in ultimate size very clearly. That the differences in growth-rate between these four groups of scallops are more or less constant is shown by the curves in the lower half of Figure 39; but that slight variations may occur from year to year can be seen by comparing this set of curves with that for the six-year group. In the latter, there was very exceptional growth in the Gulliver's Head scallops during their second year. This resulted in their growth approaching during this year (1929) very close to that of the Annapolis Basin scallops. Over a long period of time, however, the latter grew considerably faster during their second year than do the Gulliver's Head scallops.

There is undoubtedly a certain amount of overlapping of frequencies in the widths of ring-spaces on shells from these four localities; and it is in this very case that the value of statistical analysis is therefore greatest in separating and assigning significance to the differences that occur between the various means.

(3) Different Age-Groups; same places.

To obtain as significant results as possible, similar results were worked out for three different stations, corresponding to the three outer stations of the four mentioned above. The second year of growth was selected as being that which would indicate yearly variations the best, by reason of its great extent; and was determined for as many age-groups from each place as was possible, by averaging the widths of the second rings in the scallops belonging to these groups. The series, representing the growth during all the summers from 1924 to 1932, is graphically shown in Figure 40. It can at once be seen that great variation exists, not only from year to year in growth, but also between the various stations. Furthermore, all three curves follow the same general trend; and if it had been possible to obtain large numbers of shells for all the age-groups represented, it is probable that this correlation would have been even more marked. It should be noticed that whereas 1924 was evidently a poor summer in the Bay of Fundy for scallop-growth, 1929 was an exceptionally good one. In 1929, the growth of young scallops was so rapid that a year later we find the particular age-group whose second-year's growth was, in 1929, actually as large in mean size as practically all the other age-groups had been at a year older. In other words, three-year-old scallops and four-year-olds were of approximately the same size (at the Gulliver's Head Station). That this rapid growth evidently played a very important part in the survival of this particular age-group can be seen by a glance at Figure 22, which clearly shows the predominance of this age-group in samples taken from the same bed three years later.

Perhaps one of the most significant conclusions to be drawn from these results is that the time it takes scallops in one particular place to attain the commercial size may actually vary quite considerable from age-group to age-group. The scallops spawned off Gulliver's Head during the summer of 1928 attained this size in about three summers, whereas most of the other age-groups in this particular locality took four.

It has thus been shown that variations among the scallops of the Bay of Fundy occur within each age-group, from age-group to age-group, and between the same age-groups in different places. It is now necessary to discuss briefly the environmental factors to the influence of whi(these scallops these scallops have been exposed, and to attempt to correlate these factors with the growth-rate.

The possible factors in determining the nature of the scallop's environment, and hence its mode of life, are probably many and very varied. However, as mentioned above, they may be classified under the three headings---Chemical, Physical and Biotic. Under chemical factors would be classed salinity, pH, etc.: under physical, light, temperature, current-strength and geological nature of the bottom: while under biotic would be such important factors as food-supply, predators,

AGE-GROUPS	3 yrs	4 yrs.	5 yrs.	6 yrs.	7 yrs.	8 yrs.	9 yrs.	10 yrs.	11 yrs.
Station 2	33.3	36.8	37.1	43.6	33.2	33.3	32.2	33.2	31.9
No. of shells	40	30	21	100	7	3	8	11	20
Station 3	32.5	33.3	34.1	36.2	34.0	33.2	30.8	32.3	29.1
No. of shells	15	20	8	42	20	21	12	9	10
Station 5	---	---	26.0	31.4	28.2	26.6	24.2	25.4	25.6
No. of shells	0	0	4	33	31	28	12	13	18
Year of growth	1933	1932	1931	1930	1929	1928	1927	1926	1925

TABLE XIV. Mean aggregate growth during the second year in scallop-shells from three different stations in the Digby area, and comprising a series of nine consecutive age-groups. Stations 2,3, and 5 are respectively 3,8, and 12 miles off-shore in the Bay of Fundy.

parasites, etc. It has as yet only been found possible in the course of this investigation to consider, with relation to the foregoing growth variations in Digby scallops, a few of the more important of these factors: viz., temperature, food-supply, turbidity and light, and current-strength. For salinity we can refer to other papers: and this is also necessary in the case of currents. Although it is believed that the influence of the slight p^{H} changes that probably occur would be practically negligible, at the same time it is hoped that a study of this phase can be made at some time in the future.

Two series of hydrographic and plankton stations were established for the observations upon environmental factors. They are as follows:

SERIES I. Across the Bay.

Station A. Annapolis Basin, just outside the Racquette, Digby, three fathoms at Low Tide.
Station 1. Just outside Digby Gut buoy. Ca. 1½ miles off-shore 35 fathoms.
Station 8 3 miles N. Point Prim. 40 fathoms.

Station 7 6 miles N. Point Prim.42 fathoms.

Station 3	8 "	"	"	"	48	"	"Snow Ground"
Station 6	9 "	"	"	"	50	"	
Station 5	12 "	"	"	"	45	"	
Station 4	15 "	"	"	"	46	"	

Station 2 3 " N.N.W. Gulliver's Head. 45 fathoms.

SERIES II. Along the Nova Scotia shore, 2½ miles off-shore.

Station 20. Opposite Barbourville, N.S. 22 fathoms.

Station 21.	"	Margaretville, N.S.	23	"
Station 22	"	Port Lorne, N.S.	33	"
Station 10	"	Parker's Cove, N.S.	40	"
Station 24	"	Delap's Cove, N.S.	40	"

Station 1 (2 miles off-shore). Opposite Digby Gut, 42 fathoms.

Station 2 Three miles N.N.W. Gulliver's Head, 45 fathoms

Station 12. Opposite Centreville, N.S. 43 fathoms.

Station 11. W.N.W. Sandy Cove, N.S. 47 "

(1) Temperature.

It is well known that temperature variations exercise a very profound effect upon the rate of metabolism of most poikilothermic animals This is reflected in corresponding changes in the growth-rate of these forms. Apart from the direct effect it has upon metabolism, temperature may influence the growth-rate of scallops in a variety of ways that are indirect. Galtsoff (20) has shown that an increase in temperature considerably increases the activity of the branchial ciliary motion in oysters, and this results in faster feeding and a consequently higher growth-rate. Conversely, there is a low temperature at which the ciliary motion ceases altogether; and under these conditions the oysters cannot feed at all, and there is no growth. Such is very probably the case with the scallops during the colder part of each winter. Again, temperature, by determining largely the growth of plankton organisms, can in this way determine the relative abundance or scarcity of the scallops' food supply.

The scallops of the Bay of Fundy, except during the brief two or three weeks of their free-swimming larval period, are concerned only with the temperatures of their immediate habitat, the bottom. The diurnal temperature cycle of the atmosphere may extend for a short distance beneath the surface of the water, but a glance at Figure 43, and Table XVII, will show that this influence stops long before the bottom of the Bay is reached. The temperatures represented were taken soon after mid-day, at which time the influence of the atmospheric temperature might be expected to be near its maximum.

Thus the temperatures of the scallops' habitat show practically no diurnal variation. However, over long periods of time, the influence of solar irradiation and atmospheric heat does change the bottom temperatures to a certain extent, and we find an annual cycle of temperatures at the bottom, that lags considerably behind that at the surface.

The temperature of the water varied as the distance of the water from the source of heat--i.e. depth. The bottom of the Bay of Fundy at its centre is slightly deeper than the sides, and, as might be expected, a corresponding gradient of bottom temperatures can be demonstrated (Fig. 41 and Table XV). The fact that in the centre of the Bay there is a relatively larger volume of water to be heated up than at the margins also probably helps to explain this gradient. This is probably the principal explanation of the lag in bottom temperature of the off-shore as compared with the in-shore grounds at the end of the summer (See the bottom curve on Figure 41).

It is to be noted that this gradient in temperatures from the shore outwards corresponds with the gradient in growth-rate of the Fun scallops over the same series of stations.

There also exists a bottom-temperature gradient along the Nova Scotia shore. Bottom-temperatures were obtained at a series of station extending from off Margaretville to Sandy Cove (Table XVI and Fig 42). The depth of the water in this series ranges from 23 fathoms off Margaretville to 47 opposite Sandy Cove, but in this case there is not a gradient in the bottom temperatures corresponding with depth. The gradient does extend from Margaretville to Gulliver's Head; but beyond this point, the bottom temperature rises quite definitely down to Sandy Cove. However, this may possibly be explained by a regular outwash of the warmer waters of St. Mary's Bay through Petite Passage.

It is interesting to note that the distribution of scallop-beds off the Nova Scotia coast in this area does not coincide with this series of temperatures. The greatest concentration of Scallops is found north of Digby Gut; but the temperatures here correspond with those existing off Sandy Cove, where practically no scallops are found.

STATIONS

DATES	A	1	8	2	7	3	6	5	4
August 1,2; 1935	12.6	---	---	8.4	---	8.4	---	---	---
August 8,9; 1935	---	9.2	8.8	8.4	8.3	8.0	7.9	7.8	7.7
Aug. 15,16; 1935	13.4	---	---	9.7	---	8.7	--	8.1	---
September 9;1935	11.8	10.5	10.8	11.3	10.3	9.6	--	--	---
Sept 13 ;1935	----	----	----	9.6	----	10.4	--	---	---

<u>TABLE XV</u>: Bottom Temperatures (°C) at a series of stations extending north from Digby into the Bay of Fundy.

STATION NO.	MILES	Date	BOTTOM TEMPERATURE
21	0	August 29, 1935	11.5°C.
22	10	" 29, 1935	11.1
10	23	" 29, 1935	10.9
24	31	" 29, 1935	10.5
1	39	" 29, 1935	10.2
2	48	" 30, 1935	9.5
12	56	" 30, 1935	10.1
11	65	" 30, 1935	10.9

<u>TABLE XVI</u>. Bottom Temperatures at a series of stations in the Bay of Fundy, 2.5 miles from the Nova Scotia shore.

DEPTH	TEMPERATURES	
	Station 2. Aug. 9	Station 3. Aug. 8
0 fathoms	12.4°C	15.4°C
2 "	10.6	12.8
5 "	9.5	12.1
10 "	9.1	9.9
45 "	8.4	8.0

<u>TABLE XVII</u> Vertical distribution of temperatures at two stations in the Bay of Fundy, Aug. 8 and 9, 1935.

A close correlation appears to exist between the varying temperatures in the annual cycle and the period of growth of the scallops. At the bottom of the Bay of Fundy, the annual temperature cycle is gradual ("Prince" Station 5 temperature records) attaining the maximum about October, and the minimum generally in March. Temperature records off Digby are not yet available for a complete annual cycle: but it is probable that they would not vary extensively from those taken at "Prince" Station 5, between the Wolves and Grand Manan, as to the time of maximum and minimum.

Three age-groups of scallops on the Gulliver's Head bed were found to be plentiful enough for the determination of their growth-rate statistically during the summer of 1935. This was done by ascertaining the mean distance between the outermost ring (corresponding to winter, 1934,5) and the shell margin, at intervals between February and September. Figures 44 and 45 and Table XVIII embody the results of these measurements.

SAMPLE NO.	11A.	11B.	11C.	11D.	11E.	11F.	11G.	11H.
DATE OF CAPTURE	Feb. 20	Mar. 20	Apr. 20	May 20	June 14	Aug. 2,8.	Aug. 24,30.	Sept. 13
3-year group	---	--	2.0	2.4	4.2	7.13	7.58	10.05
No.of shells	1	--	1	4	1	9	15	11
4-year group	0.62	1.84	1.90	1.99	3.10	4.42	5.42	7.16
No.of shells	5	9	4	19	5	17	15	14
6-year group	1.01	0.29	0.50	0.87	1.97	2.91	3.02	3.60
No.of shells	15	24	28	18	40	14	20	12

TABLE XVIII. Growth-rate of three age-groups of scallops from off Gulliver's Head during summer, 1935. Measurements represent mean addition of shell, in m.m., to the last ring.

It can be seen from these that whereas growth was almost negligible up till May, it subsequently increased rapidly in all three age-groups; and this rapid increase, after an apparent check during August, was continued with even greater speed during early September. It is highly probable that the check during August was due to spawning activities, since all these scallops were mature specimens. A second factor, however, the decrease in food supply due to the summer diatom minimum, may also have been partly responsible. The rapid increase during September coincided both with cessation in spawning activities and with the fall diatom maximum. It was calculated, from observations made on the ring-widths of older age-groups, that at the time when these observations were stopped (Sept. 13) each of these age-groups had only grown about half the amount of new shell that was to be expected during its particular year of life. Hence it would appear that the growing-period was likely to extend considerably later into the winter than the middle of September. It is hoped that, later on, observations will be obtained that will complete the series and show just when the growing period ceases during the winter. Figure 49 shows what is probably, from the foregoing discussion, the form of the actual growth-curve of the scallops in Sample 11.

It is apparent, then, that the rate of growth of scallops in the Digby area varies corresponding to the surrounding temperature, between certain limits: but whether this effect is a direct one or not is not yet clear. However, it follows, then, that where the temperature range over the yearly period is relatively low (off-shore), a correspondingly low rate-of-growth might be expected, as compared to regions where the temperature range is higher (Annapolis Basin). Such has been shown to be the case.

(2) Food-Supply.

The feeding of bivalve molluscs has been shown by many investigators (Galtsoff, Belding, Orton and others) to be influenced largely in its activity by temperature. This influence, as we have seen, is indirectly through the effect of temperature upon the ciliary activity of the gills. Apart from it, probably the principal factor is the actual abundance of the food material in the surrounding water. Where much food is available, whether it is actually very abundant or whether it is brought to the mollusc in greater quantities through the agency of currents, and provided the temperature permits of growth, a high rate of growth results (Belding).

The stomach-contents of several scallops were examined microscopically at Digby, and were compared with Plankton tows taken with a No.18 net immediately over the scallop-beds. In general, it was found that the scallops did not discriminate in their diet very much. On the Snow Ground, for instance, about twenty different common plankton types were recognized in the tows during July, and in the stomach contents of the scallops, approximately the same number. A very few (about five) occurred in the stomachs and could not be found in the plankton; but only one form of importance (Chaetoceras) was plentiful in the plankton yet absent from the stomach contents. The latter contained even such spiny forms as small copepods and Balanus Nauplii. It would appear, then, that with few exceptions, the scallops consume the plankton in toto. This is supported by the fact that in the stomachs were found very large quantities of grit particles and detrital material, both very abundant in the surrounding water.

That detritus may be of great importance in the food of the oyster was shown by Peterson and Jensen (21); but Hunt (22), Martin (23), Savage (24) and Yonge (25) have more recently questioned this with regard to certain types of detritus, such as that formed from Zostera.

It would appear, however, from the close correlation (later to be shown) between the distribution of Fundy scallops and of their growth-rate, and the distribution of detritus, that the latter is of definite importance.

To obtain an idea of the relative distribution of food-material, series of tows were taken with the No. 18 net along series I of stations. These tows were horizontal or vertical. The horizontal tows were taken just off the bottom, and were of 10-minute duration. The vertical tows, from bottom to surface, were mainly instigated to verify the quantities of plankton obtained in the bottom tows, since the quantity of water strained in a vertical haul can be more accurately gauged than in a horizontal one.

Since the scallops apparently consume plankton quantitatively, it is justifiable to take as a criterion of the food-abundance the actual quantity of plankton that exists in a given volume of water. Table XXI and Figure 47 embody the results obtained from one series of such tows, as determined by the measurement of the volume of plankton obtained, after it had been settling in formaline for 24 hours. There is probably a certain amount of error in these figures, if they are taken to represent the actual amount of food material present in the water, due to the fact that the scallops do not consume the plankton absolutely in toto; but the probability is that the error is not of great significance.

This series of tows was obtained during the summer diatom minimum (August 7 and 8). It can be seen clearly that there is, as with temperature, a definite gradient off-shore at this time in the amount of food material present; and that this gradient corresponds likewise with the gradient in growth-rate of scallops over the same series of stations.

DATE	STATION NO.	HORIZONTAL BOTTOM TOW 10 minutes.	VERTICAL TOW BOTTOM TO SURFACE
August 7, 1935	A	16.0	----
August 8, 1935	1	13.8	7.0
August 8, 1935	8	8.8	5.5
August 8, 1935	2	----	----
August 8, 1935	7	9.3	6.0
August 8, 1935	3	8.1	----
August 8, 1935	6	----	5.0
August 8, 1935	5	6.2	----
August 8, 1935	4	4.3	3.0

TABLE XXI. Quantity of No. 18 net plankton at a series of stations extending north from Digby, N.S., into the Bay of Fundy; August 1935. Horizontal and vertical tows. Figures represent quantity of plankton in C.C. after settling in formalin for 24 hours.

That during the diatom maxima an entirely different set of conditions obtains was suggested towards the end of the summer, when the off-shore plankton tows provided quantities of diatoms that were equal to if not greater, than those obtained inshore. The great increase was due to the fall crop of Chaetoceras chiefly, which completely dominated the plankton. Other forms, such as Cyttarocylis, which is apparently consumed freely by the scallops, were also more plentiful. An examination of stomach contents at this time revealed *Chaetoceras* actually to be present in fair numbers, mostly in an advanced state of digestion. *Cyttarocylis*, too, was very plentiful in the stomachs: indeed, it was present in greater numbers, relative to the *Chaetoceras*, than it was in the surrounding plankton.

Evidently the increased consumption of these two forms during early September explains in part the rapid rise at this time in the curves of Figure 44.

(3) Currents.

It has been found by Belding, and others working on molluscan growth-rate, that bivalve molluscs grow considerably faster when placed in water that is moving, than in water that is stationary. This increase in growth-rate varies, within limits, with the strength of the current. Its cause has been ascribed to the increased quantity of food and oxygen that is made available to the molluscs by the current.

As yet, no measurements of Fundy currents have been made during the present investigation; and we have perforce to rely on the navigation charts for our information. According to U.S.hydrographic chart No. 610, the currents during mid-tide in Digby Gut may be as fast as 5 knots: 2 miles off-shore they are about 2 knots; while in the middle of the Bay of Fundy they average around 1.2 knots. Rough observations made during the summer would indicate that there is not very much difference between the current-speeds three and eight-miles off-shore. It is clear, however that this region is characterized by strong currents, corresponding to the high tides. According to the Tables of Tidal Currents (26), these currents are of much the same strength from the surface to the bottom; and hence the scallops are actually exposed to them.

There appears, then, to be a gradient off-shore in the strength of the tidal currents; and although this point needs verification, it is significant in that this gradient corresponds to the gradient in growth-rate of the scallops over the same area.

(4) Turbidity.

Turbidity measurements give us an approximate estimate of the combined amounts of plankton and detritus in the water, and consequently a very rough and ready relative estimate of light-penetration.

During the summer (1935) observations were made with a Secchi disc over the Digby area, and Tables XIX and XX briefly give the most important serial readings made.

DATES / STATION NOS.	A	1	8	2	7	3	6	5	4
August 2, 1935	--	--	--	19	--	19	--	--	--
" 3, 1935	--	--	17	--	--	--	--	--	--
" 8, 1935	10	27	28	--	27.5	31	35	43	43
" 15, 1935	--	--	--	29	--	31	--	39	--
" 30, 1935	--	--	--	27	--	--	--	--	--
" 31, 1935	--	--	--	--	--	28	--	--	--
Sept. 9, 1935	13	25	27	16	20	17	--	--	--
" 13, 1935	--	--	--	21	--	21	--	--	--

TABLE XIX. Turbidity, as measured in feet with a Secchi Disc, at a series of stations extending north of Digby into the Bay of Fundy, Summer, 1935.

Figure 46 graphically describes these figures. It can be seen quite clearly that there are gradients in the turbidity of the water both off-shore and along the shore, in both cases attaining a maximum (= minimum transparency of water) at the mouth of Digby Gut and in the Annapolis

Basin.

DATE	STATION NOS.	MILES	TURBIDITY (feet)
August 29, 1935	20	0	23
" 29, 1935	21	10	32
" 29, 1935	22	20	42
" 29, 1935	10	33	31
" 29, 1935	24	41	24
" 29, 1935	1	49	27
" 30, 1935	2	58	27
" 30, 1935	12	66	31
" 30, 1935	11	73	33

TABLE XX. Turbidity of water at a series of stations along the southern shore of the Bay of Fundy, 2½ miles off-shore. Figures represent feet of water through which Secchi disc was visible.

The gradient along-shore rises again towards the head of the Bay of Fundy, where doubtless the influence of the Minas Basin and the strong currents around Cape Split increase the turbidity of the water. However, it would seem evident from the turbidity contours (Figure 46) that the great concentration of detritus about Digby Gut is due to the outwash of detritus from the Annapolis Basin. The influence of this outwash extends off-shore about eleven miles, and along-shore as far as Port Lorne (25 miles) and Sandy Cove (19 miles). The greater influence up the Bay than down the Bay is attributed to the drift of the water.

That there is great variation in the turbidity of the water from time to time according to tidal, seasonal and weather conditions, was apparent during the summer. However, the observations graphically shown in Figure 46 were made at the time of the summer diatom minimum, during very calm weather: and it is believed that, since there were few diatoms to confuse the issue, they are a fairly accurate estimate of the detrital content of the surface waters.

It is highly significant to note that, not only the growth-rate of the scallops, but also their distribution, corresponds very closely with this distribution of detritus. Scallops from off Gulliver's Head and from the Snow Ground are both within the area of detrital outwash, and show little difference in growth-rate: but Yankee Bank scallops, from just outside the northerly limit of the area, show a great relative decrease in growth-rate (Figure 39).

As to the effect of detritus on the penetration of light, we can but surmise at this stage. Huntsman (27) has shown that mussels (Mytilus) may grow faster in light than in darkness: but there appears little evidence to support the application of this theory to Fundy scallops. It is obvious that deep-water scallops receive less light than shallow-water ones. Yet those from Yankee Bank (Station 5), where the water is about fifty fathoms, show much similar growth-rate to those from L'Etang, where the water is hardly five fathoms. Annapolis Basin scallops, from about seven fathoms show growth-rate far exceeding both of these. There would appear to be no correlation here.

(5) Salinity.

No observations were made on the salinities of the Digby area, but a picture of the seasonal salinity changes occurring in the Bay of Fundy is provided by Arnarud and Gran (28). They plotted isohalines across the Bay during the months of May, June and August (1932), and their results indicate that during the first two months there is no significant off-shore gradient in bottom salinities from the Nova Scotian side of the Bay. In August, there appears to be a slightly higher bottom salinity towards the centre of the Bay than close to the Digby shore : but as this difference is only in the neighbourhood of 0.5°/00, it is probably negligible in influencing the growth-rate of the scallops.

Discussion.

Concerning the nature of their occurrence in the Digby area, the environmental factors of temperature, food-supply, currents, turbidity and its effect on light penetration, and salinity have been considered briefly. Further work will be necessary before definite conclusions can be drawn, but the fact that there seems to be a definite correlation between the growth-rate of Digby scallops and the prevailing temperature, current-strength and food-supply would seem to indicate that these factors in the environment are of greatest importance in influencing the growth of the molluscs. Of these, it would seem that food-supply was the most important, although in itself it is largely controlled by currents and temperature.

The close correlation between the distribution of the detrital outwash from the Annapolis Basin and the geographic distribution of the scallops, coupled with the presence of strong currents and suitable bottom appears to explain satisfactorily the great concentration of the molluscs opposite Digby Gut.

PART III.

THE GROWTH OF LARVAL SCALLOPS
UNDER LABORATORY CONDITIONS

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PART III. THE GROWTH OF LARVAL SCALLOPS UNDER LABORATORY CONDITIONS

1. 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 to 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 17), the giant scallop spawns periodically, the time of actual spawning corresponding to the time just subsequent to 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 immediately. 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 50). 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 moveable 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 XXII summarizes the conditions to which each experimental jar in both temperature and salinity experiments was exposed.

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 supernatant liquid. However, when the trochophores began

Jar	Salinity	Light Conditions	Maximum Temperature	Minimum Temperature	Mean Temperature
$A_1$1	30 °/oo	Dark inside C-T box	3.0°C.	1.5°C.	2.16°C.
$A_2$1	" "	" " " "	5.7	4.9	5.26
$A_3$1	" "	" " " "	9.4	9.0	9.20
$B_1$1	" "	" " " "	10.8	9.6	10.32
$B_2$1	" "	" " " "	12.6	12.0	12.34
$C_1$1	" "	" " " "	14.7	13.6	14.37
$C_2$1	" "	" " " "	16.1	15.0	15.52
$D_1$1	" "	" " " "	17.8	16.9	17.42
F1	" "	Daylight off wharf at surface	14.4	12.5	13.42
A11	27.5°/oo	Dark inside C-T box	6.0°C	4.4°C.	5.06°C.
A12	" "	" " " "	9.3	8.4	8.95
A13	" "	" " " "	12.5	12.3	12.42
A14	" "	" " " "	14.5	13.7	14.20
A15	25.0°/oo	Dark inside C-T box	6.0°C.	4.4°C.	5.06°C.
A16	" "	" " " "	9.3	8.4	8.95
A17	" "	" " " "	12.5	12.0	12.36
A18	" "	" " " "	14.5	13.7	14.20
$A_2$2	20.0°/oo	Dark inside C-T box	5.7°C.	4.9°C.	5.21°C.
$A_3$2	" "	" " " "	9.4	9,0	9.24
$B_2$2	" "	" " " "	12.6	12.0	12.34
$C_1$2	" "	" " " "	14.6	13.6	14.27
$A_2$3	15.0°/oo	Dark inside C-T box	5.5°C.	5.0°C.	5.26°C.
$A_3$3	" "	" " " "	9.4	9.0	9,20
$B_2$3	" "	" " " "	12.6	12.0	12.34
$C_1$3	" "	" " " "	14.6	13.6	14.27
$A_2$4	10.0°/oo	Dark inside C-T box	5.5°C.	5.0°C.	5.26°C.
$A_3$4	" "	" " " "	9.4	9.0	9.20
$B_2$4	" "	" " " "	12.6	12.0	12.34
$C_1$4	" "	" " " "	14.6	13.6	14.27
$A_2$5	5.0°/oo	Dark inside C-T box	5.5°C.	5.0°C.	5.26°C.
$A_3$5	" "	" " " "	9.4	9.3	9.35
$B_2$5	" "	" " " "	12.6	12.3	12.45
$C_1$5	" "	" " " "	14.4	13.6	14.0

TABLE XXII. Summary of laboratory conditions to which experimental pint-sealers containing developing scallop-larvae were exposed.

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 convenience's sake, the stages were divided up and numbered as follows:

Stage 1. Eggs unsegmented, with or without polar bodies

Stage 2. Early segmentation and blastula.

Stage 3. Gastrula with or without cilia.

Stage 4. Trochophore.

Stage 5. Veliger.

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 $(30^{\circ}/_{oo} - 5^{\circ}/_{oo})$. With regard to light conditions, these 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 end 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.

II. EXPERIMENTAL RESULTS

(a) 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 XXIII). 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.

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

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

Date	August 17	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Hours' Duration	0	1½	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

TABLE XXIII. Development and survival of scallop-larvae kept at a mean temperature of 2.16°C. Maximum Temp. -3.0°C. Minimum Temp. -1.5°C.

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 XXIV constitutes the series of counts made upon the larvae in this jar.

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,

Date		Aug. 6	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10	Aug. 11	Aug. 12	Aug. 13	Aug. 14	Aug. 15	Aug. 16
Hours' Duration		0	3½	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

<u>TABLE XXIV</u>. Development and survival of scallop-larvae kept at a mean temperature of 5.26°C. Maximum Temp. -5.7°C. Minimum Temp. - 4.9°C.

however, the rate of growth was considerably diminished, and about eighty 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 XXV shows the counts that were made in this jar.

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

Date	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10	Aug. 11	Aug. 12	Aug. 13	Aug. 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

TABLE XXV. Development and survival of scallop-larvae kept at a mean temperature of 10.32°C.

Maximum Temp. - 10.8°C.
Minimum Temp. - 9.6°C.

temperature 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 the developmental rate at the higher temperature 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 XXVI refers to jar C_2.

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

Date	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug 9	Aug. 10	Aug. 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

TABLE XXVI. Development and survival of scallop-larvae kept at a mean temperature of 15.52°C.
Maximum Temp. - 16.1°C.
Minimum Temp. - 15.0°C.

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 (18) 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, be 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_1 and B_1) growth was on the whole quite healthy, and the trochophores, when they began to swim, did so with such 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 unfavorable 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.

(b) 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°C., 9.0°C., 12.4°C. 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‰) 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 subnormal. 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 at 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°C., 8.95°C., 12.36°C. and 14.20°C. comprise the temperature range. Table XXVII constitutes the results from jar A_{15}. In all the jars in this series, the actual experiment was begun at the termination of $3\frac{1}{2}$ hours subsequent to fertilization. Hence the counts for the first four hours cannot be taken into account in drawing conclusions from the experiments.

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_{21}, 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 that 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 XXVIII).

Date		Aug. 17	Aug. 17	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 22	Aug. 23	Aug. 24	Aug. 25	Aug. 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.

TABLE XXVII Development and survival of scallop-larvae kept at a salinity of 25°/₀₀, and a mean temperature of 5.06°C.
Maximum Temp. - 6°C.
Minimum Temp. - 4.4°C.

Date		Aug. 17	Aug. 17	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 22	Aug. 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

TABLE XXVIII. Development and survival of scallop-larvae kept at a salinity of 25°/₀₀, and a mean temperature of 8.95°C.
Maximum Temp. -9.3°C.
Minimum Temp. -8.4°C.

In Table XXVIII 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.

Tables XXIX and XXX consist of the corresponding results for 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.

Date		Aug. 17	Aug. 17	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 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 XXIX. Development and survival of scallop-larvae kept at a salinity of 25°/∞ and at a mean temperature of 12.36°C. Maximum Temp. -12.5?C. Minimum Temp. -12.0°C.

Date		Aug. 17	Aug. 17	Aug 18	Aug. 19	Aug. 20	Aug. 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

TABLE XXX.

Description of TABLE XXX. Development and survival of scallop-larvae kept at a salinity of 25°/∞ and at a mean temperature of 14.20 °C.
Maximum Temp. -14.5°C.
Minimum Temp. -13.7°C.

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 XXVII - XXX. As in the first series of experiments, the rate of development varied with the temperature.

The actual salinity of 25°/∞ appears to allow this development at the higher temperatures that were studies, 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°/∞) and $A_2 1$ (30°/∞) show a very interesting difference. These jars were kept at approximately identical temperatures, and differred appreciably only with regard to salinity. In $A_2 1$ (30°/∞), 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°/∞), 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 éxtent 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 $A_3 1$, $B_2 1$ 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, $A_3 1$; and A_{18} two days shorter than C_1. A_{17} was the same as $B_2 1$. 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 vigorously 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°/oo. These correspond respectively to jars $A_3 1$, A_{12}, A_{16}, $A_3 2$, $A_3 3$, $A_3 4$ and $A_3 5$. 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.

Date	Aug. 6.	Aug; 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10	Aug. 11	Aug. 12	Aug. 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

($A_3 1$)

TABLE XXXI. Development and survival of scallop-larvae kept at a mean temperature of 9.20°C. and at a salinity of 30°/∞. Maximum Temp. -9.4°C. Minimum Temp. -9.0°C.

Date	Aug. 17	Aug. 17	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 22	Aug. 23
Hours' Duration	0	4	16	41	65	89	113	136
Stages1.	loo	loo	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 XXXII. Development and survival of scallop-larvae kept at a mean temperature of 8.95°C. and at a salinity of 27.5°ø∞.
Maximum Temp. -9.3°C.
Minimum Temp. -8.4°C.

Date	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10	Aug. 11	Aug. 12 ($A_3 2$)
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 XXXIII. Development and survival of scallop-larvae kept at a mean temperature of 9.24°C. and at a salinity of 20°/₀₀.

Maximum Temp. - 9.4°C,
Minimum Temp. -9.0°C.

Date	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10	Aug. 11	Aug. 12 ($A_3 3$)
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 XXXIV. Development and survival of scallop-larvae kept at a mean temperature of 9.20°C. and at a salinity of 15°/₀₀.

Maximum Temp. - 9.4°C.
Minimum Temp. - 9.0°C.

Date	Aug. 6	Aug. 6	Aug. 7	Aug. 8	Aug 9	Aug 10	Aug. 11	Aug. 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

($A_5$4)

<u>TABLE XXV.</u> Development and survival of scallop-larvae kept at a mean temperature of 9.20°C and at a salinity of 10°/oo.

Maximum Temp. -9.4°C.
Minimum Temp. -9.0°C.

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

<u>TABLE XXXVI.</u> Development and survival of scallop-larvae kept at a mean temperature of 9.35°C. and at a salinity of 5°/oo.

Maximum Temp. -9.4°C.
Minimum Temp. -9.3°C,

Discussion upon Series II of Salinity Experiments

In an examination of the foregoing tables, it is clear that at salinities of 25°/₀₀ 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°/₀₀ 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°/₀₀. 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°/₀₀) this occurred very soon after initial exposure of the larvae to the conditions; but at the higher salinities (15 and 20°/₀₀) 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 D.

The first effect of low salinity upon the scallop-larvae, as seen with the aid of a microscope, was 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 micromeres, 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 onle part of one. In such cases, the free micromeres were disregarded, and the largest "macromeres" taken into account alone.

(c) 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 No. 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 XXXVII shows the results obtained from this (F) experiment; the two jars giving essentially the same results.

Date		Aug. 17	Aug. 17	Aug. 18	Aug. 19	Aug. 20	Aug. 21	Aug. 22	Aug. 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

TABLE XXXVII. Development and survival of scallop-larvae kept in the jar placed one foot beneath the surface of the St. Croix River.

Maximum Temp. - 1414°C
Minimum Temp. - 12.5°C
Mean Temp. - 13.41°C

Salinity - 30/..

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 very 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 normal, 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. If 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 jar. 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.

(d) 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 always 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 51 shows several of these abnormal forms as they appeared and were drawn under the microscope. It can ben seen that, in a large number of 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.

(e) Parasites on Eggs and Larvae

During the examination of freshly-shed scallop-eggs on August 8th a and on August 17th, 1934, 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 protozoas 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-membrane. They were both watched for about half an 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 evidenced 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 th 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 52 is prepared from drawings of these protozoans made at the time of observation.

(f) 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 51; but in a very short time, they swelled up to their normal size, which was found during the summer of 1933 to be between 0.065 and 0.079 m.m. 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 particles 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 preference for either condition, remaining constantly quite equally distributed throughout the length of the dish.

Whether the larvae at this stage are phototropic 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 as 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 24th, 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.

(g) Lethal Temperatures

During the course of the summer of 1934 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 19) 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.

(i) 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 24 hours, when they were examined as to whether they had recovered or died. Table XXXVIII summarizes the results:

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

TABLE XXXVIII. Lethal temperatures of adult scallops

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.

(ii) Trochophores.

Some water from a jar in compartment B_1, containing a large number of apparently very 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 XXXIX summarizes the results, commencing at the 23.4°C. point.

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

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.
32.3	" " " Several settled to bottom and quiescent, Cilia slow.
32.5	Motion practically stopped in all. Cilia beating only feebly.
32.9	Only one or two show slight rtoary 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.

TABLE XXXIX. Lethal temperatures of Placopecten trochophore larvae.

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.

(iii) Spermatozoa

During a lethal temperature experiment that was being conducted upon some adult scallops on August 13th, 1934, several male scallops threw large quantities of sperm into the water in the tub. The first was extruded when the temperature was 18.5°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 spermatozia was determined concurrently with that of some adults. Table XL 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.

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

TABLE XL. Lethal temperature of *Placopecten* Sperm.

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 spermatozoa 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 conditions. This may or may not explain the relatively low lethal point determined; it cannot, however, be taken as a conclusion without further evidence.

S U M M A R Y

SUMMARY

The Fishery:

The Giant Sea-Scallop (Placopecten grandis Solander) is the subject of an important and steadily increasing fishery in the Fundy area. The economic value of this fishery to Canada is high, up to 91 per cent of the total Canadian scallop catch being yearly taken in this region. The capture of scallops is effected by specially constructed scallop-drags drawn along the sea-bottom by a powerfully-engined boat, generally of a design specially adapted to the work. The main areas of distribution of scallops in the Fundy area are from Brier Island to Parker's Cove in Nova Scotia, and south-east of Grand Manan Island in New Brunswick. Less extensive areas are situated off the Lurcher Shoal and along the northern shore of the Bay from Campobello Island to Point Lepreau, including the Wolves. The fishery began in the Fundy area in 1895, and from 1895 to 1920 scallops were landed in small quantities solely from the northern shore of the Bay. In 1920 the Digby fishery began, and very large quantities were landed in Digby and Annapolis counties during the subsequent years, increasing till 1927, after which a decrease was noted, to be replaced by a very great increase culminating in the peak catch of 1934-35, valued at nearly $200,000. Regulations for scallop-fishermen have been devised in order that the resources may be utilized to the best effect: but it appears that these regulations will need adjustment from time to time if they are to accomplish their purpose. The adductor muscle of the scallop is the only portion eaten at present. These are generally sold fresh on the Boston market by the "herring half-barrel." Investigation has shown that the rims, formerly considered inedible, can be utilized to make tasty scallop-paste. Otherwise the rims are largely used as cod-bait. The ground-up shells have been used as poultry grit. The future of the fishery lies chiefly in the state of the market, which it is believed can be considerably extended by proper advertisement.

The Life-History:

The life-history of Plactopecten may be conveniently classed in three stages, determined by the methods employed for studying it; the pre-veliger, the veliger, and the shelled stages. Spawning occurs during the summer, fertilization taking place in mid-water. For a greater or less period, dependent largely upon the prevailing temperature conditions, the fertilized ova rest on the bottom, until the free-swimming trochophore stage is attained, when they swim actively at all depths in mid-water. For a period of about two weeks, the trochophores, and the veligers into which they develop, swim in the water, and are distributed by the prevailing currents. They then settle upon the bottom as spat, and if the bottom and environment are suitable, they develop into adult scallops. Their growth is rapid during the first three years, attaining a peak during the second year in most cases; and subsequently slows up gradually until the maximum age, which is probably about fifteen years, is reached. There is an annual cycle of growth, which is indicated upon the shells by more or less clearly marked annual rings, that can be taken as a criterion of the growth-rate per year. These rings are deposited once a year, at the time of the lowest prevailing temperatures (early spring), and are due to the cessation, more or less complete of growth at this time. The bulk of growth takes place during the summer, probably from May until the following November. The presence of annual rings makes it possible to determine the growth-rate in different areas, and wide variation is found to occur between samples. This variation is reflected in the time that elapses between birth and the attainment of the legal size of four inches. This period varies according to locality, from barely three years off Digby to six at L'Etang Harbour, N.B.

Information has been presented that it is hoped will be of value to conservationists of the fishery in the future.

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an extra year of life before they attain legal size, they have one extra summer to spawn. Not only would this aid in maintaining the productiveness of their own beds, but due to the natural tendency of the ocean currents in the Bay of Fundy, much of the spawn would be carried up over Sections II and III and possibly even as far as Section VI.

The very successful "set" which occurred in Sections I, II and III in 1937 was by no means unknown to us until the extensive samplings of April 1940. Draggings with similar gear in 1937 revealed 15 scallops, all between 1. and 2.5 cm. in diameter. These were all scallops of one summer's growth. In that area comprising Sections II and III, dragging operations in the fall of 1938 resulted in the finding of over 140 two year old scallops in a total of 322 caught. And when it is realized that these small scallops are far less readily scraped from the bottom than are the larger ones, it will at once become apparent why the ratio for this group in 1938 was so much lower than that of 1939. With the addition of the third year's shell, this group was still more readily caught and hence the still larger ratio of this group in the samples of 1940, as is shown in Table XII.

It would, without doubt, prove very valuable to follow the supply trend of one particular age group of scallops from year to year throughout it's life, and this present three year old group of Sections I, II and III would appear to be ideal for this study.

Another outstanding point for consideration in connection with the data presented in Table XII is the characteristic absence, in all of the section sampled, of sizable numbers of six and seven year old scallops, as contrasted to larger numbers of older ones. Normally one would expect to find a gradient downwards in numbers with increase in years of age of the scallops if an equally successful "set" were experienced each year. From this expectation we can only come to the following conclusions: the seasons 1933 and 1934 must have been exceptionally poor for successful spatfalls or some factor must have caused a very high mortality in the young scallops of those two years. Fishing operations without doubt very quickly deplete each new legal size group as it appears, but at the same time continue to take from the supply of the preceeding age group so that if these six and seven year groups had been as large in number when they attained legal size as were the eight and nine year groups we would expect the reverse from which we found.

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