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Some Environmental Factors Limiting Growth and Distribution of the Quahaug, Venus Mercenaria L.

by

C. J. Kerswill.

FISHERIES RESEARCH BOARD
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TABLE OF CONTENTS

	Page
INTRODUCTION	1
GENERAL DISTRIBUTION OF VENUS MERCENARIA	5
LIFE HISTORY AND HABITS OF THE QUAHAUG	6
METHODS OF CAPTURE	8
METHODS DEVELOPED FOR GROWTH STUDIES	10
INVESTIGATION OF FACTORS LIMITING GROWTH	19
(a) Bideford river, P. E. I.	19
Salinity	22
Temperature	23
Light	27
Exposure	31
Distance below low water level	32
Bottom	33
Eel grass	34
Water circulation	36
Crowding	45
(b) Tatamagouche bay, N. S.	47
Salinity	48
Temperature	48
Exposure	48
Bottom	50
Water circulation	50
General conclusions	51

	Page
INVESTIGATION OF FACTORS LIMITING SURVIVAL AND DISTRIBUTION	53
Salinity	53
Temperature	56
Location of settlement	58
Exposure	60
Eel grass	62
Storms	65
Movement	67
Predators	70
Disease	72
Rate of growth	76
Rate of removal	77
Breeding stock	80
SUMMARY	82
REFERENCES	87
APPENDICES	91
ACKNOWLEDGMENTS	103
ILLUSTRATIONS	104

INTRODUCTION

The quahaug or hard-shell clam, Venus mercenaria L. of the Atlantic coast of North America has been investigated to some extent in the United States because of its value as a food product. When, about 1900, it became evident that the abundance of the species was rapidly diminishing in the New England states, attempts were made by Kellogg (1905) in New York state and Belding (1912) in Massachusetts, to obtain information on its life-history and growth under various environmental conditions. The latter work was quite extensive, the recommendations outlined apparently adequate, and no more research on the quahaug was attempted for over twenty years.

Investigation of the quahaug was resumed in 1935, by Mr. V. L. Loosanoff, sponsored by the U.S. Bureau of Fisheries, in Connecticut. This resulted in the publication of several papers on the early life-history (Loosanoff, 1937, a.b.c.) and the relationship of shell movement to temperature (Loosanoff, 1939).

Stafford (1912) described the free-swimming larval stages of the quahaug in plankton collections made in Canadian waters, and MacBride (1912) discussed briefly the methods of fishing quahaugs and their injurious effects on oyster culture. In 1916 a short paper was published on a supposed disease of quahaugs in New Brunswick (Cox, 1916). Except for these papers and reference to quahaugs by various fishery officers in the Canadian government reports, nothing has been published on this mollusc in Canada.

The American oyster, Ostrea virginica and the quahaug have similar distribution in Canadian waters, both being warm water forms at the northern limit of their ranges, and occurring only in situations where the sea water reaches a high temperature early in the summer (Nelson, 1928). Malpeque bay, on the north shore of Prince Edward Island has been one of the most important centres of production of both species. In this area both species were reduced by 1916 almost to extinction as a result of improperly controlled fishing and disease, as will be mentioned later. The Prince Edward Island Biological Station was established in 1930, on Bideford river, near the former centre of production of oysters and quahaugs, for the purpose of developing cultural methods whereby the oyster might be restored to the Malpeque bay area. The methods developed have been very successful, and oysters are being restored to those parts of the area where the bottom is hard and suitable for the development of well shaped stock. Other parts of the area have bottom which is too soft for oysters, but which should be suitable for quahaugs, since they did occur there at one time.

For the purpose of determining the life-history and factors influencing the rate of growth and survival of the quahaugs in the Malpeque bay area, the present investigation (sponsored by the Fisheries Research Board of Canada) was started in 1938. It was undertaken by the writer on the suggestion of Dr. A.W.H. Needler, in charge of oyster culture at the P.E.I. Biological Station, where the main part of the work has been done. An effort has been made to obtain information that will be applicable to more than the Malpeque bay area. Owing to the limited funds available as well as limitation of time, it has been possible for the writer to conduct personal investigation at only one outside area, namely Tatamagouche bay, N.S., where oyster culture investigations have been in progress since 1937. Environmental conditions there are considerably different from those in Malpeque bay due to a much greater range of tide, and may be considered to be typical of other situations where quahaugs occur on the south shore of Northumberland strait. However, collections of specimens from other locations have been examined and some idea of growth rates of quahaugs over most of the area in Canada where they occur at the present time, has been obtained.

The important parts of the investigation may be detailed as follows: (a) a determination of the present distribution of quahaugs in typical parts of the region under consideration; (b) the development of satisfactory methods of conducting growth and survival experiments with the limited stock available, so that significant results might be obtained; (c) the determination of the age of specimens; (d) the derivation of considerable information on the life-history and habits of the quahaug which would be necessary for the planning of conservation measures; (e) formulation of a plan whereby experiments could be set up to investigate the effects of a large number of environmental factors on growth and survival of quahaugs in a limited time.

Thus a large part of the work has been the development of suitable methods. These were worked out largely during the first summer, in 1938, when exploration showed where specimens could be obtained for experiments, and observations on the life-history and habits of quahaugs were begun. In the spring of 1939 a series of experiments was set up just before the start of the growing season in Bideford river and followed throughout the season, while other experiments were set up at Malagash, N.S., in the Tatamagouche bay area. During the summer of 1939 observations were made on the life-history of the quahaugs, and a number of laboratory experiments were performed to determine the ability of the quahaug to survive variations in temperature and salinity. A series of experiments was set up in the summer of 1940 in Bideford river, similar to the 1939 series, for the purpose of checking the 1939 observations, and a number of additional experiments were conducted with a view to giving more information on certain factors, for example, - circulation of water, which appeared to be important after analysis of the 1939 results. The 1940 results checked closely with those obtained in 1939 in all important features.

GENERAL DISTRIBUTION OF THE QUAHAUG

Venus mercenaria occurs on the Atlantic coast of North America from the Gulf of St. Lawrence southward to the Gulf of Mexico (Johnson, 1934). This is considered to be its natural habitat and its occurrence in some places on the Pacific coast is attributed to accidental planting with eastern oysters. It is essentially a southern warm-water form, occurring only in the more sheltered and shallow bays and rivers at the northern part of the range, where its distribution parallels that of the American oyster, Ostrea virginica (Belding, 1912).

Definite information on the bathymetric distribution of Venus mercenaria is lacking. In Massachusetts its range is given by Belding (1912) as from high-tide line to a depth of over 50 feet. It is not known to occur at any depths greater than this in Canadian waters.

Information on the distribution in Canada has been obtained in several ways. One source of information on past distribution is the Fisheries Statistics, published by the Dominion Government, showing the centres near which quahaugs have been caught and landed. Dr. A.W.H. Needler is familiar with the present distribution of quahaugs on Prince Edward Island and has furnished information for districts which the writer has been unable to visit. In 1939 and 1940, Dr. R.A. Ingalls of Mount Allison University, surveyed the mollusc resources for the Nova Scotia Economic Council and his notes on quahaugs have been kindly forwarded to the author. A considerable number of fishery officers, mollusc fishermen, and others have been interviewed and valuable information on the past and present distribution has been obtained from them. Personal exploration has been carried on as much as possible.

The above information has been incorporated in figure 1, where it will be seen that quahaugs are limited to Prince Edward Island and the Northumberland strait shores of New Brunswick and Nova Scotia. The records from the Fisheries Statistics do not indicate that there was a wider range of distribution in the past, except perhaps along the north shore of Prince Edward Island, but there is no definite information that quahaugs are now absent from these places.

LIFE-HISTORY AND HABITS OF THE QUAHAUG.

In the study of the factors limiting growth and distribution special attention has been given the life-history and habits.

Quahaugs usually live just under the surface of the sea bottom, but sometimes on hard bottom of the intertidal zone in an exposed situation the dorsal portion of the valves and the ligament are uncovered. Their proximity to the surface as compared to other borrowing species like Mya arenaria is necessitated by the very short siphons which project only a few millimetres beyond the posterior edges of the valves. Large quahaugs about 6 to 8 cm. long are inactive although they are provided with a powerful foot. If left on the surface of the sea bottom in summer they bury themselves in a short time, but once below the surface practically no horizontal movement occurs. Observations over several months on many specimens of this size have shown no horizontal movement whatsoever. Smaller quahaugs are more active, and specimens 2 to 3 cm. long have been found to travel distances up to one foot in two summer months. Very small quahaugs, about 5 mm. long, have a larger foot relative to the size of the valves and are more active than the larger sizes in burying themselves, but move very little horizontally. All sizes are able to regain the surface if they have been buried under several inches of bottom during summer.

Quahaugs are inactive at low temperatures. Loosanoff (1939) found them to remain closed at temperatures below 5° or 6°C.,and that they were open from 69 to 90 per cent of the total time at temperatures above 11°C. In May 1939 at the P.E.I. Biological Station, when the temperature of the water was around 10°C., specimens left on the surface of the sea bottom did not bury themselves for several days, while in midsummer they have usually disappeared from view in less than an hour.

Loosanoff (1937a) made an exhaustive study at Milford, Conn., of the development of gonads of <u>Venus mercenaria</u> by means of serial sections, and concluded that the sexes are usually separate and that spawning as males may occur in the first season of growth and as either males or females in the second season. In Bideford river, spawning has occurred in 1939 and 1940 after the temperature in late June and early July at the bottom has reached about 23°C., and continued until about September 1st. Fertilization occurs in the sea water and a trochophore larva develops, followed by a veliger larva with a shell called a prodissoconch. The veliger larva swims by a velum until the shell has increased from an initial length around 0.1 mm. to 0.45 mm.; when a foot has developed, the velum disappears, and the larva settles to the sea bottom or other firm surface. In 1939, the length of the free-swimming period was estimated by identifying particular broods of larvae in successive plankton tows from spawning to settlement and found to be around 12 days. After settlement, a shell, characteristic of the adult, develops and is called a dissoconch. The foot has a byssal gland which can produce a single thread byssus for attachment of the small quahaugs under 10 mm. in length.

Owing to the shortness of the growing season, the growth rate in Venus mercenaria in Canadian waters is slow, and at least 5 years and often longer is required for the minimum marketable length of $1\frac{3}{4}$ inches to be attained. On the other hand, the length of life is considerable, since specimens up to 25 years of age (determined by the growth-ring method described on page 12) are frequently found.

METHODS OF CAPTURE

The method of fishing depends upon the location of the quahaug beds and the kind of bottom. In situations below low water level where the bottom is not too hard, a large rake, provided with a wire screen basket behind and above, on a long handle 25 to 30 feet in length, is operated from a dory. The rake is thrown out from the anchored boat and slowly worked in toward the fisherman. When under the dory, the rake is turned over and the contents brought to the surface. The contents of the basket are then washed back and forth to free them of mud and sand, and the quahaugs picked out. On hard bottom below low water level an adaptation of the oyster tongs is sometimes used. This consists of a pair of rakes with long curved teeth, pivoted about four feet from the rake end, which is lowered toward the bottom with rakes apart, and thrust into the bottom; the rakes are then brought together and the contents raised.

On the intertidal zone quahaugs are obtained by hand picking at low tide, either after the bottom has been dug up with a rake or spade, or after the position of the animal has been determined by 'treading' the bottom bare-footed. If the beds are covered by only a few inches of water as the tide is receding, the position of the quahaugs can often be determined by searching for the dark open ends of the siphons.

When heavy rakes or tongs are used in fishing, many specimens are damaged. It has been found, however, that although considerable damage may occur to the shells, the quahaugs survive.

At Ellerslie in 1939, specimens damaged in various degrees, were planted in a bed and examined a month later. It was found that specimens which had considerable pieces of the shell broken away to expose the mantle, had not survived. Those having shells merely cracked right across or whose valve edges were chipped without much mantle being exposed had survived, and the breaks in the shell were being filled in.

It may be concluded that shells slightly cracked or shipped may be repaired and no mortality will result. But, badly broken shells resulting from careless handling of the rakes or other implements may result in considerable mortality of specimens in quahaug beds.

METHODS DEVELOPED FOR GROWTH STUDIES

At the beginning of the investigation in 1938 the problem of developing suitable methods for conducting growth studies of the quahaug arose. Kellogg (1903) held individual specimens in flower-pots, planted large numbers in beds in different situations and held others in wire racks above bottom, measuring the length before and after the experiments. Belding (1912) followed Kellogg's method of planting experimental beds in numerous locations and held specimens in boxes at different depths suspended from rafts. He evidently had much assistance and unlimited stock of suitable size for the experiments, because hunereds of beds were planted and their growth followed. Weymouth (1923) in an investigation of the life-history and growth of the Pismo clam (Tivela stultorum) in California, showed that growth rings were a true indication of age in this mollusc. His whole investigation depended upon this method of age determination, as the rates of growth of clams in different situations were calculated from measurements of the annual rings of large collections of specimens. Belding (1912) says nothing about growth rings as a method of age determination for the quahaug, and considers the age of specimens only when they had been reared for a known length of time. He made use of a method of notching the edge of the quahaug shell with a file at time of measurement so that the growth during a subsequent interval of time could be seen readily, the file mark leaving a permanent record on the shell.

In the summer of 1938 exploration of Bideford river in the vicinity of the Biological Station showed that it was difficult to obtain small specimens of uniform size for experimental plots. Several locations were found where suitable quahaugs could be obtained more readily than in other places, and throughout the summer enough were dragged to establish 8 beds, 4' by 2' in area, each containing 50 measured and notched specimens. The beds were planted along a line running out from the shore of Bideford river, from near high water mark in hard sandy bottom to beyond low water mark where the bottom becomes a mixture of sand and mud and gradially gets softer as the proportion of mud increases. Several lots of measured and notched quahaugs were planted in wire screen boxes such as were used in growth experiments with Mya arenaria by Newcombe (1935) and sunk into the bottom, but it was soon evident that these were very unsatisfactory for growth experiments with the quahaugs here, because the wire tops became clothed in algae and little growth occurred in them, as compared to growth in beds nearby. It was found that no appreciable movement of quahaugs planted in beds occurred during the summer, thus the necessity of enclosing them in any was was removed. The recovery of specimens from beds planted in the intertidal zone was found to be comparatively easy, as they could be felt for with the hands, or the bottom raked up at low tide when they could be seen and picked. It was found difficult to recover specimens from beds beyond the water level by dragging, and some other method of following growth in deep water proved to be necessary.

In 1938 it appeared that growth rings would be reliable indices of the age of quahaugs. The regularity in the width of bands on the shells of specimens raked throughout the summer, was noticed first, then the increasing width of the lighter-coloured new shell beyond the last check-mark as the season progressed, was observed. Specimens raked late in the summer had a final band of lighter colour than the rest of the shell, and of about the same width as previous bands. In general, larger specimens had added narrower bands than smaller specimens, and this was in accordance with the width of previous bands on these specimens. Previously-notched specimens recovered from the experimental beds showed lines on the shells at the position of the notch similar to the other check-marks between rings, but always fainter. Similar indefinite lines sometimes were observed between the definite check-marks, apparently marking the interval between growing seasons, but these were always distinguishable from the latter, especially at the ends of the shell where they were barely discernible. In a small proportion of specimens from Bideford river and Paugh's creek there ware so many lines throughout the shell that it would have been difficult to read the age, but less than 5% of the specimens were in this condition. The large numbers of rings may have been due to frequent disturbance of the quahaugs by oyster raking in these situations where the bottom was soft, as quahaugs from harder bottom in p;aces where they would be undisturbed did not show such disturbance rings. In none of the specimens held in beds during the summer were any lines produced other than those which arose at the time of notching. In the spring of 1939 examination of specimens from the planted beds showed the addition of a narrow bank of shell beyond the last check-line which had been made at the time of notching in the previous fall, and there was, in some specimens, a very slight amount of growth visible beyond the check-line of the 1938-39 winter, which was as yet evident only at the posterior ends of the shells where the growth had occurred. Examination of a sample lot of specimens from the beds planted in 1938 and undisturbed until the fall of 1939, showed in all cases the definite winter check-line slightly beyond the last notching line of 1938, followed by the growth of the 1939 season, which was in every case free of any check-lines.

In the first attempts to read the age of quahaugs from growth rings, the chief difficulty was in determining the extent of the first season's growth. This was due to the wearing away of the shell in some specimens in the region of the umbo, and to the inturning to some extent of the first-formed shell as the shell increased in size, and the valves produced early in life were spread apart. Nothing was known of the size that quahaugs reached during the first season in this region. Collections of quahaugs spawned in 1938, and found attached to oyster collectors in Bideford river late in the season, showed the small size reached in several months' growth, and further collections os small specimens from Malagash, N.S., in 1939, showed what size might be expected for quahaugs at the end of the first season. It is now possible to determine the check-line produced at the end of the first growing season in most cases, as it is much nearer the tip of the umbo than was first expected.

After the preliminary work of 1938, the following general methods of conducting growth studies were adopted in 1939. They proved to be satisfactory and were used again in 1940.

Collections of specimens were made as early as possible in the spring in the same location from which the number of similar lots os specimens required for experiments were made up. For example, in the spring of 1940, enough specimens were dragged near the mouth of Paugh's creek in five days by Mr. Colin Hutchinson, an experienced quahaug fisherman, to provide 25 similar lots (of 73 specimens each), with a size range of 17.5 to 43.5 mm., height, and a mean height of about 32 mm. for each lot. The specimens for each lot were picked by a method of random sampling which gave similar size composition to each, and a size-frequency distribution similar in form to the normal curve.

At the start of the experiment in 1939 the dimensions of each specimen were measured with a vernier caliper to the nearest tenth-millimetre. The usual measurements of bivalves are length (the greatest antero-posterior dimension of the valves), height (the greatest distance from umbo to ventral margin of the shell), and thickness (the greatest width through the two valves perpendicular to the long axis). The ventral margins of all the shells were notched lightly with a three-cornered file, and each time the specimens were recovered during the growing season, for measurement,. At the end of the growing season a record of the extent of growth in each of the growth intervals was visible on the shells, since the notches could be seen plainly.

In 1940, when a greater number of specimens was used in each lot, in order to save time in getting the experiments set up and in returning the specimens to the water after taking them up at intervals throughout the growing season, all the measurements were made at the <u>end</u> of the growing season. The specimens were notched at the start of the experiments, and again when recovered. A light check-line is produced on the shell at the time of notching, and measurements can be made of the size to the end of any period in the fall.

It was found in 1939 that the most convenient dimension to measure on the quahaug shell is height, and it was decided then to use height as the size dimension throughout all the growth experiments. When determinations of age were attempted by reading growth rings and the size measurements at the ends of various years were desired, the advantage of height measurement over length measurement was found.

In quahaugs small ridges having nothing to do with the annual check marks, are produced on the surface of the shell parallel to the growing edge. They are less evident over most of the shell surface after the first few years of growth and do not hinder the reading of check marks near the middle of the valves. At the ends of the valves, however, they are always quite prominent and make difficult the reading of the check marks. The height of a quahaug shell is greater in proportion to the length than in most bivalves, as shown in figure 18 (Ht.= 0.92 L.), and the accuracy of the measurement is therefore about the same. Also, since the umbo has a definite position, the error in applying the vernier caliper for the height measurement is only half as great as the error when the calipers are applied to the two ends of the annual rings, since an estimation of the position to set the calipers must be made at both ends.

Measurements of the three dimensions, length, height and thinkness were made for all specimens at each time of measurement in 1939, and from these the relationships between height and length and height and thickness have been plotted. (Fig.18) Determinations by water displacement of the volume of various sizes of specimens have also been made, and the height-volume relationship is shown in figure 18. In 1940 measurements of length and thickness were made for only a few lots where a change in shape was thought probable.

Growth in the intertidal zone and for a short distance beyond low water level was determined by planting each lot of specimens in a bed 4 ft. by 2 ft. in size, with the corners of the bed marked by stakes. The quahaugs could be recovered at low tide by feeling for them with the fingers.

Growth in deeper water was studied by planting each lot of specimens in a wooden tray 4 ft. by 2 ft. in area and 6 in. deep, the wood being 1 inch thick and coated with special paint for protection against shipworms. After filling the trays with the required type of bottom material, rope bridles were attached and the trays were either placed on the bottom with tarred ropes leading to buoys at the surface, or hung at any desired depth from a pole supported by wooden tripods. Such a tray when filled and ready to put out weighs several hundred pounds but it can be handled conveniently by four men, if towed just below the surface between two dories, and lowered carefully at the required location.

To determine the effect of light and circulation of water on growth, special trays were constructed. They will be described later when these factors are discussed.

Newly-settled quahaugs: On the shore of Tatamagouche bay, by measuring specimens obtained from bottom screenings at different times during the growing seasons of 1939 and 1940, the growth of small quahaugs in their first two years of life was followed.

Larvae: Attempts to follow the growth of the free-swimming larval stages were made in 1938 by taking plankton tows over quahaug beds in Bideford river with a net of No.18 silk bolting-cloth, throughout the season. The larvae of about a dozen species of bivalves are present in such tows and the recognition of quahaug larvae presented some difficulty, especially in the early stages. Stafford (1912) illustrated what he considered to be quahaug larvae in plankton tows taken in Malpeque bay, and larvae similar in size and appearance to these were found in small numbers in the 1939 tows. Early in 1939 a large bed of quahaugs was planted just below low water level in Bideford river and tows were taken regularly over this bed. Much greater numbers of the same larvae as found in 1938 plankton tows occurred in these tows, and it was possible to follow several 'broods' until they disappeared from the water, when a few were found to have settled on oyster collectors nearby. The later stages of larvae have a characteristic umbo, which coupled with the large size of the larvae, makes them unmistakable but it was still uncertain whether these younger straight-hinged stages, found by working backward through tows taken previously, were the same as those described by Stafford.

Accordingly several attempts were made to obtain larvae by inducing adult quahaugs to spawn in the laboratory, but these were all unsuccessful. The quahaug does not respond to increase of temperature and the presence of genital products of other ripe quahaugs by spawning as do the oyster and mussel. This was also found Loosanoff (1937c) who was successful in getting quahaugs to spawn in the laboratory in only a very small proportion of cases.

An attempt was them made to fertilize auahaug eggs artificially, by addition of male gonad to ripe eggs in sea water. After several unsuccessful experiments a few motile trochorphore larvae were obtained on July 29, 1940, when eggs and sperms were taken from quahaugs which had apparently shed less than half their spawn. On August 6th, 1940, the experiment was repeated; successful fertilization occurred, and straight-hinged larvae had developed by August 8th. Camera lucida drawings and measurements were made, and these checked with those of Stafford. This is apparently the first time artificial fertilization of quahaug eggs has been observed. Loosanoff (1939c) reported numerous unsuccessful attempts and attributed the negative results to the inability of the germinal vesicle of the egg to break down when the egg is outside the ovary. This dissolution of the germinal vesicle is the crusial step preparing the egg to be fertilized by the sperm, and according to Loosanoff it never occurs if the ovary is cut, even if the quahaugs are in the act of spawning at the time. This theory is disproved by the present results.

In 1940 it was not possible to follow "Broods" of quahaug larvae in the tows because there were quite large numbers of mature larvae continuously after the first appearance of umbo stages on July 16th. Evidently quahaugs do not spawn in marked bursts like oysters and mussels, whose broods of larvae can be easily followed in successive tows, but the production of larvae by quahaugs appears to be a gradual process extending over a long period when the water temperature is sufficiently high. The relationship of spawning to temperature will be discussed later.

INVESTIGATION OF FACTORS LIMITING GROWTH

Bideford river, P.E.I. experiments. (a)

In 1939 twenty-four plots, each containing 50 small specimens, were set out in Bideford river at the beginning of the growing season. They were arranged as shown in figure 4a to demonstrate the effect on growth of kind of bittom, position on intertidal zone, depth below low water level, crowding, eel-grass, exposure to light, etc. In 1940 twenty-five plots each containing 73 specimens were set out as shown in figure 4b. These experiments were a repetition of those set up in the previous year with the addition of several to give more information on the effect of circulation of water on growth.

The method developed for treatment of the measurements consists of plotting histograms to represent the size-frequency distributions in each plot at the beginning and at the end of a certain growth period. The histograms for all the plots are similar and are distributed about the same mean height (to within 1 mm.) at the start of the experiments. Comparison of growth between different lots during a time interval can be made by observation of the distance traversed by the histograms along the size axis. The histograms representing the data obtained in the experiments of 1939 and 1940 are shown in figures 10 to 14. Since the experimental plots were arranged so that one plot could provide data on several factors wherever possible, the plots concerned in the discussion of each factor have been gathered on separate pages.

The mean heights of each lot at the beginning and at the end of the experimental are shown on the diagrams, as well as the standard errors of the means.

There has been very little variation (usually not more than 0.5 mm.) in the final size of quahaugs having the same initial size, which were held in the same situation. Consequently the histograms representing the size-frequencies at the beginning and at the end of a growth period are very similar in form. Also, the standard errors of the final mean heights of different lots exhibit little variation, and they are slightly less than the standard error of the initial mean heights. This is a result of a more rapid increase in height on the part of the smaller specimens, causing them to overtake some of the larger specimens, with a consequent reduction in the spread of the histograms.

It has been decided that a difference in final size between two lots of specimens shall be considered insignificant unless there is an obvious difference in the positions of the histograms representing these lots. Such a judgment of significance is made possibly by the constancy in the form of the histograms as pointed out above. Where there is no definite difference in position of two histograms, but a small size difference is shown by comparison of the mean final heights, a trend may be indicated, but the significance of the difference is held in doubt unless the same observation was made upon repetition of the experiments.

From the calculated values of mean height and standard error, an estimation of the statistical significance of differences between the final mean heights of different lots can be made by application of the 't' test for small samples, as described by Fisher (1934), or Goulden (1939). This test has been applied in a number of cases to determine how great the difference between two means of the present population need be, to consider them liable to occur by chance in no more than 5% of total trials (the generally-used level of significance set for biological investigations). For example, applying the test to two final mean heights obtained in the 1940 experiments, when such heights differ by 1.6 mm. and have a standard error of the difference amounting to 0.8 mm., the probability of this difference occurring by chance is 5%, or 1 in 20. In the present series of experiments from the fact that the same specimens are measured at the beginning and at the end of the growth periods and their individual identity is known, coupled with the slight variability in growth of different specimens of the same size, it should be safe to assume a slightly higher level of significance. However, in discussing the significance of the results below, unless there is good reason to believe otherwise, (as for example when a definite trend is in evidence along a series of plots) differences are considered of doubtful significance when the probability of their occurrence by chance is greater than 1 in 20.

In 1939 a series of plots containing similar lots of 50 mixed sizes of quahaugs ranging in height from 25 to 75 mm., was set up parallel to the series containing only small sizes (figure 4a). The purpose of this series was to compare growth in different sizes of quahaugs, and also to compare growth in Bideford river and Malagash basin, where similar lots of quahaugs were planted in the spring of 1939. The measurements of these lots at the beginning and end of the 1939 growing season, have been grouped into height classes of 10 mm. range, and the average increase in height of each class has been calculated. These calculations are tabulated in Appendix 2.

Salinity.

Salinities were taken at intervals throughout the period of open water in 1939 at four hydrographic stations as shown in figure 2. While considerable differences in salinity occurred between stations 2001 and 2007 for example, in the spring, following the melting of snow and ice and spring rains, and again late in the fall, there were slight differences in salinity at each of the four stations throughout most of the growing season. In 1939 about 70% of the season's growth occurred between July 13th and September 6th, and at no time were there differences of more than $1\frac{1}{2}$ mille between different stations.

The remarkable similarity in salinities throughout Malpeque bay and its inlets or river is pointed out by Needler (1931) who states that there is usually no more than several parts per mille difference between the upper ends of the inlets like Paugh's creek and the open bay. It can be concluded that salinity may be disregarded as a factor of any importance in limiting the growth of quahaugs in different parts of the Malpeque bay area.

Late in September, 1939, a collection of quahaugs was obtained from two of the tributaries of Paugh's creek to determine how far up toward the heads of the creek quahaugs might be found. The upper limit where breadth of the inlets is only about 50 to 75 feet, is shown in figure 2. The growth of these specimens as shown by annual rings was no less than the growth of specimens obtained near the mouth of the creek, where fresh water would be at the surface following rains and not affecting the salinity of the whole stream, as it would in the shallow and narrow upper heads of the inlets.

Temperature.

To determine the correlation between seasonal growth of quahaugs and temperature, sample lots of speciemns were taken up at intervals throughout the growing season for measurement, and temperatures at the beds were recorded daily by maximum and minimum thermometers. These were supplemented by temperatures taken daily except Sunday from the end of the landing stage. The plots in trays (position 5, fig.4) containing sandy mud just below low water level will be considered as examples, since temperatures were taken nearby.

In 1939 the specimens were set out on June 1st and in 1940 on June 11th, both these lots having been fished within the previous week and held on the bottom near low water level until needed. No growth was visible on the specimens before these dates. This was in contrast to oysters of similar length, which had grown considerably, about one half inch of new shell having been formed by some. The times of recovery of the quahaugs for measurement depended upon the condition of the tides and pressure of other work, and in 1939 they were recovered on July 13th, August 6th, September 6th and finally on November 6th; in 1940 recovery was possible at monthly intervals, on July 12th, August 12th, September 12th and finally on November 15th just before freeze-up.

The maximum and minimum temperatures taken throughout 1939 and 1940 have been plotted in figure 6. Some criterion was desired by which temperatures effective for growth might be indicated, and upon examination of the temperature graphs and the growth of the specimens, it appeared that the season's growth occurred during that time when the minimum water temperature was above 10°C. That the minimum temperature for growth lies somewhere around 10°C., is also suggested by the work of Loosanoff on shell-movement in Venus mercenaria (Loosanoff, 1939) where he found hibernation to occur in most clams when the water temperature fell below 5° and 6°C., and the average period of openness of the valves to reach 88% of the total time only when the water temperature had reached about 11°C.

If the horizontal line be drawn across the record at 10°C. and the area between this line and the minimum temperature line calculated, a possible expression of effective growth temperature in day degrees can be abtained. Comparison of the growth during each period and these 'effective temperatures' are shown in the following table.

Table 1.

Time intervals between measurements.	1939				
	Before June 1	June 1 to July 13	July 13 to Sept.6	Sept.6 to Nov.6	Total
GROWTH					
Actual Height increase	0	2.6 mm.	5.8 mm.	0.6 mm.	9.0 mm.
Percentage of whole	0	29%	64%	7%	100%
TEMPERATURE					
Number day-degrees over 10°C.	40	280	567	100	987
Percentage of whole	4%	29%	57%	10%	100%

Time intervals between measurements	1940					
	Before June 11	June 11 to July 12	July 13 to Aug. 12	Aug. 13 to Sept.12	Sept.13 to Nov.15	Total
GROWTH						
Acutal Height increase	0	1.6 mm.	212 mm.	416 mm.	015 mm.	8.9
Percentage of whole	0	18%	25%	52%	5%	100%
TEMPERATURE						
Number day-degrees over 10°C.	56	162	292	236	94	840
Percentage of whole	7%	19%	35%	28%	11%	100%

In 1939 when the interval July 13th to Sept. 6th was not sub-divided, a rather close correspondence existed between the percentage growth and percentage temperature during each period. In 1940 when the growing season was divided into shorter periods the size increase was greatest during August 13th to Sept. 12th., while the average highest temperatures occurred from June 13th to August 12th. Evidently other factors than temperature are of major importance in controlling the growth during different parts of the summer, as, for example food, spawning, etc. However, the growing season as a whole is delimited by temperature as the primary factor.

Bottom temperatures taken at four stations from 2001, in the upper part of Paugh's creek, to 2004 in Malpeque bay (Fig.?), at intervals throughout the 1939 growing season are plotted in figure 7. Comparison of temperatures taken at 2001 and 2007 shows that the different growth rates exhibited by quahaugs from these two situations (Fig.17) are not likely a result of temperature differences, since the 2001 temperatures are usually slightly higher than temperatures at 2007. Similarly quahaugs taken from Paugh's creek to clean beds just west of 2003 grew faster than in their old location, but there is little, if any, temperature difference between the two places, the temperatures at 2003 being lower than 2001 temperatures throughout 1939.

Light.

While quahaugs generally live entirely buried in the bottom except for the siphons which come to the surface, they are sometimes partially exposed on shores where severe wave action takes place. Again, they have been found in considerable numbers entirely on the surface, among mussels in the intertidal zone of the Basin, Malagash, N.S. Dr. A. G. Huntsman (1921) showed that light has a marked effect on the growth and shape of small mussels exposed under glass, causing them to grow less and to be blunter than specimens held under similar conditions, but in the dark. It was thought that an experiment designed to show the effect of light on the growth of quahaugs might give interesting results, especially if mussels and oysters were included for comparison.

A floating tray, 12' by 4' by 6', with wooden sides, and ½" wire cloth bottom similar to those used in the rearing of small oysters was constructed in the spring of 1939. The inside was divided by wooden partitions into eight equal compartments. Alternate compartments were covered by wooden lids and the others were covered with "Celloglass", a flexible transparent medium reinforced by window screening. All the wood was coated with a special paint for protection against shipworms. One lot of quahaugs was placed in each of the four compartments at one end of the tray. Each of the remaining four compartments was subdivided by wire cloth and one lot of oysters and one lot of mussels were placed in adjoining subdivisions. The tray was moored (as shown in figure 4a) where it would be protected as much as possible from the wind. Such a tray is floated largely by the lids which lie just at the water surface.

The tray was examined at intervals of a few days throughout the summer when any growth of algae was removed, and the specimens were scattered if they had become clustered. In the lighted compartments there was more growth of algae than in the dark, while in the latter a heavy settlement of mussels occurred during the summer, none having appeared in the lighted compartments. When the experiment was repeated in 1940 there was not as heavy a growth of algae as in 1939, but the set of mussels was similar. In neither year was the growth of algae sufficient to clog the wire screen of the tray bottom nor was there enough present between times of cleaning for any expected effect on growth by decreased circulation. The greatest difficulty was in keeping the mussels separated as they quickly formed clusters, attaching themselves to one another and to the tray bottom by their byssi.

In figure 12 the 1939 growth of quahaugs in the light and in the dark may be compared. All the light and all the dark specimens were considered together in that year, but in 1939 the data for each of the four compartments are shown separately. Very little difference shows in the final size of quahaugs held in the light and dark. In 1939 the dark specimens had a slight advantage, but the situation was reversed in 1940, and light may be considered to have no significant effect on growth rate of quahaugs. It is to be noted that growth in the floating tray was considerably less than on clean beds and trays filled with soil. As Belding (1922) pointed out, quahaugs held out of the bottom do not grow as well as those normally buried.

Comparison of the growth and shape of quahaugs, mussels and oysters in the light and in the dark is made in the following table.

Table 2.

Species	Mean size at start	No.	Mean size at end	No.	Size increase	Ratio T/L
DARK						
	mm. Length		mm.		mm.	
Venus mercenaria 1939	28.5 ±.4	95	37.3 ±.3	95	8.8 ±.5	.54
1940	31.1 ±.5	145	35.1 ±.5	145	4.0 ±.5	-
Mytilus edulis 1939	Length 24.6 ±.3	50	36.1 ±.4	45	11.5 ±.5	.37 ±.003
1940	14.0 ±.06	60	28.5 ±.1	45	14.5 ±.2	.38 ±.009
Ostrea virginica 1939	L/W 2 ; 20.4 ±.3	50	50.5 ±.6	50	30.1 -.7	.33
1940	21.3	10	49.6	10	28.3	.27
LIGHT						
Species	Mean size at start	No.	Mean size at end	No.	Size increase	Ratio T/L
	mm. Length		mm.		mm.	
Venus mercenaria 1939	28.5 ±.4	97	36.3 ±.4	97	8.1 ±.6	.54
1940	31.4 -.4	131	35.9 -.5	131	4.5 -.6	-
Mytilus edulis 1939	Length 25.2 ±.3	50	34.5 ±.5	44	9.3 ±.6	.37 ±.003
1940	14.1 ±.1	60	25.8 ±.3	49	11.8 ±.3	.40 ±.006
Ostrea virginica 1939	L/W 2 ; 21.4 ±.3	50	41.3 ±.9	45	19.9 ±.9	.37
1940	22.8	7	43.8	7	21.0	.33

As an index of shape the ratio thickness/length was calculated for the quahaug and mussel lots, while the ratio thickness/average of length and width was calculated for the oysters. The small number of oyster measurements for 1940 is due to most of the specimens having been lost when a severe storm on September 16th washed away the covers of the lighted compartments.

During both years mussels grew more in length in the dark. In 1939 there was no difference in the mean values of T/L, but a small number of specimens from the lighted compartments had the peculiar blunted appearance found by Dr. Huntsman (1921), and none in the dark had such an appearance. In 1940 the mussels were kept separated throughout the summer to a greater extent than in 1939 and the blunted appearance was evident to some degree in most of the specimens. The average value of T/L was greater for the light specimens in 1940.

Oysters grew considerably more in the dark compartments than in the light and the thickness was greater at the end of the growing seasons in the light. Oysters have a better shape when the thickness is greater in proportion to the other dimensions and with this end in view it might be advantageous to expose small oysters to light.

It may be concluded that exposure to light has no effect on size or shape of the quahaug, while oysters and mussels grow less in length but tend to thicken when exposed to light.

Exposure.

In both 1939 and 1940 four beds were planted from just below high water level to just beyond low water level (Fig.4).

To determine the water coverage throughout the growing season, a tide clock was operated on the landing stage and the heights of water, at which each bed was just covered, were set on the tide records. In the following table are shown the proportions of growth at each bed to growth just below low water level, and the proportion of time each bed was covered with water.

Table 3.

Bed position	1939 Coverage Total hrs.	%	% Growth	1940 Coverage Total hrs.	%	% Growth
1	144	3.8	(died) 0	753	34.1	18.4
2	1549	40.3	14.6	1550	70.1	43.6
3	3777	98.5	100.0	2204	99.7	100.0
4	3840	100.0	95.0	2208	100.0	95.8

The results of these experiments are shown in figure 10, and also the better growth in bottom trays than in beds is shown.

In 1940 beds 1 and 2 were slightly lower in position than in 1939, while in both years there was very little difference in coverage at 3 and 4. Better growth occurred in both years at bed 3 than at bed 4, but this may be explained by the presence of eel-grass near position 4, rather than by difference in coverage. (see "Eel-Grass" later).

In the above table it may be seen that the proportion of growth is always less than the proportion of coverage, showing that the number of hours that a bed is covered by water is not the only factor controlling growth. Variations in temperature accompanying exposure at low tide, are always more marked at higher levels (fig.8). The amount of food available for quahaugs may be affected by exposure of the sea bottom to air at low tide. The evaluation of these and other factors affecting growth in the intertidal zone is not possible at the present time.

Distance below low water level.

In 1939 the growth of quahaugs in the bottom tray at position 7, 5 feet below low water level, was slightly less than in the trays 5 and 6, just below low water level, and the growth in the bottom tray at position 8, 10 feet below low water level, was slightly less than at position 7. (Mean heights on September 6th were 39.6 ± .6 at No.5, 38.2 ± .5 at No.7 and 36.8 ± .5 at No.8)

Repetition of the experiment in 1940 with an additional bottom tray 7½ feet below low water level showed that slower growth need not be expected in the deeper situations unless there is some obstruction to circulation such as the presence of eel grass. Growth at position 8, 7½ feet below low water level, was the same as at position 5 in bottom trays where no eel grass was near, the final mean heights of these lots being 39.5 ± .6 and 39.7 ± .6 respectively (figure 13, No.8, 1940; figure 10, No.5, 1940). At position 7, 5 feet below low water level, growth was considerably less than at either position 5 or 8(figure 13, No.7) and exploration showed that there was eel grass around the tray, while none occurred near the other trays. At the deepest position, No.9, 10 feet below low water level, the growth was slightly less than at No.8 (figures 13, 14) and no eel grass or other obstruction was found there. Considerable difficulty was experienced here in getting the tray out of the mud since the bottom was very soft. It is possible, however, that this tray had sunk lower than the tray at No.8, giving less circulation of water similar to the bed at low water level, where the same final height of 38.1 - .7 (figure 11, No.13) was attained.

Bottom.

The kinds of bottom in which quahaugs commonly occur may be classified as (a) firm sand, and (b) rather soft sandy mud, called "rubber bottom". The former is characteristic of the shallower beds extending from the intertidal zone outward to sand bars or shoal areas where the bottom is largely free of muc. The latter is found in deeper water just beyond the hard bottom of oyster beds, where quahaugs once occurred in abundance.

To compare growth in these two types of bottom, plots were set up in bottom trays, No.5 containing sandy mud from beyond low water level, and No.6 containing clean sand from the intertidal zone. In 1939 the growth of each lot was the same as shown in figure 11. In 1940 a growth of eel-grass occurred in Bideford river just outside the low water level and was very close to several plots along this line. The sand tray at No.6 was affected in this way while the mud tray at No.5 was some distance from the eel-grass.

As a result probably, the 1940 mean growth in the sand tray was slightly less, amounting to 7.1 mm. in height as compared to a mean increase in height of 8.4 mm. in the mud tray.

It may be concluded from the 1939 results, where there was no difference in the surroundings of the two trays, that kind of bottom does not influence growth rate.

Eel grass.

Before its almost complete disappearance, in 1931 and 1932, from the southern part of the gulf of St. Lawrence (Huntsman 1932), eel grass, *Zostera marina* L. was very abundant in areas where quahaugs occurred. A noticeable increase in the abundance of eel grass has been observed from 1938 to 1940 in the Malpeque bay area. It is probable therefore that many areas wehre quahaugs could be raised will soon be covered by the plant, and its effect upon growth and survival of the quahaug has been given considerable attention.

To determine the effect of eel grass on growth, beds were planted on clean bottom and on grassy bottom in Bideford river. In 1939 the most convenient patch of eel grass was off Mr. Fred England's property on the north shore of Smelt creek (figure 4a) Two plots of specimens were set out here, No.12 on clean bottom, and No.13 about 6 feet away on bottom covered by thick eel grass. These were left over most of the growing season, from June 13th to September 26th. In 1940, owing to the spread of eel grass since the spring of 1939 it was possible to locate a bed, in thick eel grass at 17 (figure 4b), for comparison with the clean beds at the same level.

The results of the experiments are shown in figure 13. Specimens in beds covered by thick eel grass grew considerably less than those in clean beds nearby.

On September 27th, 1939, a collection of quahaugs was made on the east shore of Paugh's creek (figure 2b) where eel grass was quite plentiful but not as thick as at plot 13 (figure 4a). From this collection a sample was drawn, showing similar size-frequency distribution at the start of the 1939 growing season to that of the experimental plots. Histograms for this sample are shown in figure 13, for comparison with those of a clean plot at 4, (figure 4a). The growth, near the mouth of Paugh's creek where eel grass occurred, was much slower than on the clean bottom at No.4. Temperature and salinity conditions at these two locations are very similar (figure 7).

At the end of the 1940 growing season results differing from those of 1939 were obtained on several plots just west of station 2003. Examination of the bottom showed that eel grass was present on or close to these plots. For example, bed 4 was similar in position to bed 13 but it was partially surrounded by eel grass while bed 13 was surrounded by clean bottom for a radius of 10 feet. The growth of specimens in bed 4 was intermediate between the growth in beds 17 and 13.

Lot 7 in a bottom tray 5 feet below low water mark grew much less than lot 8 in a similar tray 7½ feet below low water mark and 100 feet farther out. Examination, in September, of the bottom with oyster tongs showed that lot 7 was located just on the edge of the patch of eel grass while the bottom at 8 was clean.

It may be concluded that quahaugs in a bed covered by dense eel grass grow much more slowly than quahaugs in a clean bed, and even thinly-distributed eel grass has a noticeable effect on growth. Moreover growth is considerably hampered where eel grass does not grow on the bed itself but merely occurs close by.

Further consideration of eel grass will be given under the heading "Water circulation".

Water circulation.

Several observations on the growth rate of quahaugs in the 1939 Bideford river experiments suggested the importance of water circulation as a factor limiting growth:

(a) Quahaugs, as shown by the eel grass experiment on the north shore of Smelt creek, grew much more in a clean bed than in a bed nearby with similar environmental conditions, except that tha latter bed was covered with eel grass (figure 13).

(b) Similar lots of quahaugs planted on June 1st on the bottom of Bideford river in beds and in wooden trays resting on the bottom at the same level, but with the specimens raised off the general river bottom a distance of six inches, exhibited significant differences in growth (figure 14). A possible explanation of the faster growth in the trays was that as a result of friction with the general river bottom, the rate of flow of water six inches above the bottom was greater than the rate of flow on the bottom.

(c) The growth bands on quahaugs held on clean bottom in beds near low water level, (just west of station 2003 (figure 2)) throughout the 1939 growing season, were considerably wider than the growth bands of previous years, which had been added when the specimens were living near the mouth of Paugh's creek at B. The growth bands added in 1939 by similar specimens at B were also found to be significantly narrower than the bands added near 2003. When investigation of the bottom at B was made, and eel grass was found scattered over the beds, it appeared that circulation of water might be the factor of major importance responsible for the growth difference. Temperature and salinity conditions at the two locations are almost identical, and while the bottom at the mouth of Paugh's creek contains slightly more mud, the kind of bottom has been found to have no significant effect of growth rate.

(d) As determined by measurement of growth rings of quahaugs sample from each location (figure 17), the growth rate of quahaugs fished near the low water mark on the south shore of Bideford river near 2007 was faster than the growth rate of specimens obtained up-river at B (figure 2). Temperature and salinity conditions at the two locations are very nearly the same (figure 7) throughout the growing season, and there were no other obvious differences in physical and chemical conditions except circulation of water. At 2007 the current is quite noticeable when the tide is rising or falling. At B. toward the head of tide, little effect on floating objects can be noted at any stage of the tide, and a very light breeze is sufficient to neutralize tidal current in the upper few inches of the water.

The possibility that the nature and abundance of food is a factor influencing growth rate must not be overlooked. There is no reason to suppose that food conditions in Paugh's creek and in Bideford river at 2007 are different, and it is generally considered that water in the upper parts of inlets is richer in the microscopic forms suitable for bivalves than is the more open water of rivers and bays.

These observations in 1939 led to the repetition and extension of experimental work on the effect of water circulation on growth in 1940. In addition to bottom plots on the shore of Bideford river a vertical series of hanging trays was set up near the middle of the river. A special experiment was set up in which similar lots of quahaugs and of oysters for comparison were held in trays inside boxes permitting different degrees of circulation. A Gurley current meter suitable for measurement of currents in situations where currents are slow, was borrowed from the Department of Hydrographic Service for several weeks in September. Measurements of currents in several situations with this meter have shown how the rate of flow of water varied in different situations where the growth rate of quahaugs was followed. The 1940 experiments on circulation of water are described below.

(a) Box Experiment.

This experiment was designed to determine the effect of different amounts of circulation of water on the growth of similar lots of quahaugs and similar lots of oysters.

Three wooden boxes, similar except for the ends, were constructed of half-inch lumber, with dimensions 3' 8" long, 2' wide and 1' high. The ends of one were covered with fox wire of 1 inch mesh, another with wooden slats spaced ½" apart, and the third was board over and six ½" holes were bored evenly spaced in each end. The wood was coated with a special paint for protection against shipworms and a layer of cement 1" thick was placed in the bottom of each box to hold it stationary on the river bottom. Trays of ½" galvanized wire screening with dimensions 2' by1½' by 4" were contructed and divided longitudinally into two compartments. These were suspended by wires in the boxes to give a similar space between tray and the box all around. Tarred rope bridles for lowering and raising the boxes were attached and white stripes were painted on the box covers so that their alignment on the river bottom could be seen from a boat.

On June 19th, in one compartment of the tray of each box, were placed similar lots of 73 notched quahaugs, and in the other compartments were placed similar lots of 75 measured oysters (1939 spat). The boxes were then lowered to the bottom of Bideford river, near hydrographic station 2003 (figure 4b), where the depth of water is about four feet at low tide. An oyster bed is situated here giving a firm bottom and there is no eel grass or other obstruction for at least one hundred feet in any direction. A lot of quahaugs similar to the other three was placed at the same time in mud, half filling an open-topped wooden box of size 2' by 1' by 1', which was set on the bottom nearby. This sample, therefore, was surrounded by a solid wall 6" high, and the growth could be compared with the growth of similar lots 200 feet to the west which were held at the surface of mud filling wooden trays.

On July 17th the boxes were taken up and the contents examined. All the specimens were alive and there was no fouling by sea-weed, etc. They were returned to the original positions and not taken up again until September 13th when the specimens were removed, measured and weighed. The mean size of the oysters and quahaugs in the three boxes at the beginning and at the end of the experiment, and the weights of each lot at the end of the experiment are shown in the following table.

Table 4.

Box				Venus mercenaria					
	H at start	No.	H at end	No.	Total wt.	L - W at start	No.	L-W at end	No.	Total wt.
	mm.		mm.			mm.		mm.		
No.1 closed	31.6 +.7	73	33.0 +.7	73	1032 g.	24.7 +.3	75	28.1 +.6 (34 dead)	41	299 g.
No.2 medium open	30.8 +.8	73	34.3 +.5	73	1266 g.	24.7 +.3	75	47.6 +.7	74	1299 g.
No.3 open	31.1 +.8	73	35.7 +.6	73	1459 g.	24.7 +.3	75	48.9 +.7	74	1511 g.

All the quahaugs survived in the three boxes; growth was least in the box with ends almost completely closed and best in the box with end open, while in the box with ends partially closed by slats the final size of specimens was just midway between the final size in the other two boxes. 45% of the oysters in No.1 box died and there was little growth in those which were alive. All the oysters lived in boxes No. 2 and No. 3, but the final sizes of these two lots were very similar, considering the extent of growth as compared to the quahaugs.

Histograms representing the size of the three lots of quahaugs at the beginning and at the end of the experiment are shown in figure 14, for comparison of growth with other lots held in situations with different amounts of water circulation.

(b) Vertical series of trays:

At the start of the growing season, three trays of the regular type containing mud bottom and similar lots of 73 specimens each were hung from a pole supported on tripods in the middle of Bideford river at 10, 11, 12 (figure 4b). In conjunction with 9, which was on the bottom 10 feet below low water level, 10 was $7\frac{1}{2}$ feet below low water mark and 12 was $2\frac{1}{2}$ feet below low water mark. Histograms of the sizes of each of these lots at the beginning and at the end of the 1940 growing season are shown in figure 14. The growth of these plots will be discussed later along with others concerned in water circulation.

(c) Current measurements with the Gurley meter.

The Gurley type current meter consists of four light aluminum cups set at right angles to one another about a vane which is pivotted to rotate freely when suspended in a current. With each rotation an electrical contact is made which causes a click in an earphone worn by the observer. The rate of flow of water is determined by timing a number of rotations of the vane and referring to a calibration table supplied with the instrument. A current with velocity of at least 0.25 feet per sec. is necessary to turn the vane of the meter and reliable absolute measurements are not possible for velocities less than 0.50 feet per sec.

It was found that bottom currents in Bideford river in the vicinity of the experimental plots could not be measured with the instrument as they were too slow, but surface currents caused by moderate winds could be determined.

To compare the rate of flow of water along the bottom with the current at various distances from the bottom, measurements with the Gurley meter were made, off the end of Lennox island wharf, about 3 miles down river from the Biological Station (figure 2). The current here was found to be sufficient for the operation of the meter at all depths, and readings were made from bottom to surface just after the turn of tide on August 23, 1940. Similar measurements were made at Malagash, N.S., on September 9th and 10th, in the channel at the entrance to the Basin (figure 3). The times for 10 or 20 revolutions of the vane are given in Table 5, where as many as possible of the readings have been translated into actual velocities.

These measurements show that the current at a distance of 2 feet above bottom is almost twice as fast as the current at the bottom, and generally increases toward the surface of the water.

Summary of circulation results and conclusions.

The effect of different degrees of circulation of water on growth of Venus mercenaria is shown clearly in figure 14, where lots 22, 23, 24, 25, and 5 are arranged in order of the amount of circulation allowed the specimens. A regular increase in the ultimate size of the quahaugs with increased circulation of water

Table 5.

Current measurements with Gurley current meter.

Locality	Date	Depth	Average time	Number Revol-utions	Number obser-vations	Velocity feet/sec.
Bideford river at Lennox Is.	Aug. 23, 1940	Bottom (40')	105 sec.	10	3	0.25
		2' above bottom	56 "	10	2	0.43
(Tide ½R)		4' "	39 "	10	2	0.59
		6' "	37 "	10	2	0.66
		8' "	35 "	10	1	-
		10' "	33 "	10	1	-
		12' "	37½ "	10	1	-
The Basin Malagash, N.S., off Clarke's point	Sept. 9	Bottom (12')	76 sec.	10	7	-
		2' above bottom	50 "	10	6	-
		Bottom	75 "	10	2	-
(Tide ¾R)		4' above bottom	37 "	10	5	-
		6' "	45 "	10	4	-
		Bottom	101 "	10	2	-
The Basin, Malagash, N.S., off Clarke's point	Sept. 10	Bottom (12')	90½ sec.	20	4	0.52
		2' above bottom	50½ "	20	4	0.91
		4' "	59 "	20	1	0.78
		6' "	55⅞ "	20	7	0.83
(Tide ½R)		10' "	36 "	20	2	-

is seen. The difference in growth between quahaugs of lot 24 and lot 5 is due to the former lot being held on wire screening and not normally buried in bottom. The same difference between the growth of similar lots of quahaugs held on clean wire screening and held buried in mud in trays is shown by comparing the ultimate size of specimens held in the floating light experiment tray (figure 13, 1940), with the size attained in a hanging mud-filled tray near the surface (figure 14, No.12). Belding (1912) also observed this difference in his experiment.

The histograms for lots 9 to 12 on figure 14 show a regular increase in the final size of quahaugs from the bottom 10 feet below low water level at the middle of Bideford river toward the surface at the same place. The difference in growth at the different heights was not very great and of doubtful significance, but the final size attained in the uppermost tray, No.12, was the greatest of any of the Bideford river experimental plots and doubtless a result of good circulation of water near the surface of the river as a result of wind currents. While the water currents toward the bottom of Bideford river at this location were not strong enough for measurement by the Gurley meter, readings could be taken in the upper several feet when a moderately strong wind was blowing.

The faster growth of Venus mercenaria when held in bottom trays and thus raised about six inches off the bottom, then when the specimens were planted in the same kind of bottom as a bed nearby (figure 10, 1939 Nos.4 and 5; 1940 Nos.4 and 5) may be explained in the light of the Gurley current meter measurements.

The rate of flow of water at a distance of two feet above bottom was always found to be about twice as great as three inches above bottom, which was the nearest to the bottom that the meter could be operated. A similar, though probably not as great, difference would be expected between the bottom and a distance of six inches above bottom.

Growth of quahaugs held in the closed box (lot 22, figure 14) was of the same order as grwoth in the plot covered by thick eel grass (lot 17, figure 13). This supports the view that the slower growth in eel grass is a result of decreased circulation of water.

The importance of good circulation of water to the rapid growth of quahaugs is demonstrated by these experiments. Differences in growth rate of quahaugs in different locations (e.g. Bideford river at 2003 and at 2007) where other environmental conditions are similar, may be explained on the basis of differences in the amount of circulation of water.

Crowding.

In 1939, beds 9, 10 and 11 were established just beyond low water level to determine the effect of crowding on growth. The size of bed 9 was 4' by 2' and the specimens were about 6" apart; bed 10 was made 2' by 1' with the specimens about 2½" apart; bed 11 was 1' by 6" and the specimens were closely crowded and touching one another. In 1940, beds 13, 14, and 15 were established in the same manner but the area of each was slightly greater to accommodate the larger number of specimens (73) and with the same intervals between them as in 1939 when only 50 specimens were in each lot.

The histograms in figure 11 show a remarkable similarity in the final size of each lot at the end of the experiment in both years. It may be concluded that close crowding of quahaugs in beds does not influence growth rate.

It is reasonable to suppose that crowding would result in decreased growth rate if there was an attendant shortage of food, either due to decreased circulation or to an insufficient food supply for each member of a large number of specimens crowded into a small area. In molluscs normally buried in the bottom and separated at least by the thickness of their valves, such crowding is less likely to occur than in forms like the oyster or mussel which are not buried and liable to form dense clusters.

At the start of the 1940 growing season, to determine the effect of close crowding of quahaugs held above bottom, one lot of 73 specimens was mixed with 200 more and the whole lot placed in a basket of ½-inch wire cloth, which was suspended 2 feet below low water mark from tripods at position 16 (figure 4b).

Measured on September 11, 1940, very little growth was found on any of the specimens (figure 11). Compared with the similar lot 18 held for the same length of time on a floating tray in a compartment 3' by 1' by 6", with bottom of ½-inch wire cloth, the growth in the crowded basket was insignificant.

Thus it may be concluded that close crowding of quahaugs which are buried normally in the sea bottom need not result in less growth than if they were well spaced. However, little growth should be expected if quahaugs are packed into crates in large numbers, as is done sometimes by shippers.

(b) Tatamagouche bay, N. S.)

In 1939 five beds of quahaugs as shown in figure 3 were planted in Malagash basin, and left through the growing season. Each consisted of 45 specimens of mixed sizes ranging from 25 to 75 mm. in height, because sufficient numbers of small quahaugs could not be found to make up lots like those of the small series in Bideford river. During the summer many specimens were killed by Polinices heros.

Measurements of specimens which were recovered alive have been placed in classes having class intervals of 10 mm., for comparison with the data of the Bideford river series of mixed sizes. These data are tabulated in Appendix 2. Close similarity between growth at the two locations is shown.

In 1939 and 1940, uniform samples of the settlement of quahaugs of the previous year, were taken at 50-foot intervals from high water level out to low water level on the shore of Tatamagouche bay (E. figure 3a). Size-frequency distributions (figure 15) have been prepared from measurements of (i) the growth during the season when settlement occurred (by measuring to edge of growth ring produced at first winter), and (ii) the growth until late in the second summer. Growth of small quahaugs at different levels can be compared by examination of these histograms.

Collections of quahaugs made in Malagash basin from the channel at C (figure 3) and from the beach nearby at F (figure 3), exhibited different rates of growth. Current measurements were taken at the two locations, to determine whether significant differences in water circulation might be correlated with the differences in growth rate.

Salinity.

Bottom salinities in Malagash basin have been taken daily (with few exceptions) throughout the open water period of 1939 and 1940, at three stations, numbered 1, 2 and 3 (figure 3). There has rarely been a difference in salinity of more than 1 per mille between these stations. Plotting the salinities taken at station 2 shows that after marked fluctuations during May and early June, a steady value between 28 and 30 per mille was reached and maintained throughout the growing season (figure 9). Therefore salinity conditions are very similar to those in Bideford river (figure 7), and it would not be expected that growth of quahaugs at the two locations would differ as a result of this factor.

Temperature.

Bottom temperatures taken at stations 1, 2 and 3 at the same times as salinities, rarely differed by more than 1°C. A graph (figure 9) of the temperatures taken at station 2 shows a remarkable similarity to the Bideford river temperature graph (figure 7).

In 1939 no difference was found between the length of the growing season at Malagash basin and in Bideford river. Quahaugs obtained for growth experiments had grown none before June 1st, and no noticeable growth occurred after September 20th, when the specimens were taken up, notched and returned to the beds until November 1st.

Exposure.

As a result of different tidal amplitude and different characteristics of the tide, exposure of the intertidal zone in the Tatamagouche bay area differs from that of the Malpeque bay area.

In both locations a declinational tide prevails, so that a diurnal tide, having only one high and one low water period in a day, occurs at intervals when the range is greatest. In Malpeque bay the tidal amplitude averages about 3 feet, the intertidal zone is narrow, and when the range of tide is greatest there is a single, short, daily high, and a very long, low tide. This results in severe exposure of the intertidal zone. In Tatamagouche bay the ~~tix~~ tidal amplitude averages about 8 feet, the intertidal zone is much wider, and during periods of maximum tidal range, the tide does not hang for prolonged lengths of time at the low water position. It is only for several days each month that the intertidal zone below half-tide level is exposed at all. Thus there are extensive areas of intertidal zone in Tatamagouche bay where exposure would not be expected to be a limiting factor to growth.

This explains why quahaugs at the half-tide level in Malagash basin grew as well as at outer levels,and in the dyke where there was complete coverage, while in Bideford river the growth at half-tide level was much less than at positions near low water level.

Exposure does not appear to limit the growth rate of small quahaugs at different levels on the intertidal zone of Tatamagouche bay, throughout the area inhabited by them. In 1939 and 1940, uniform samples of the settlement of the previous year were taken at 50-foot intervals from high water level out to low water level at E (figure 3). Size-frequency distributions of the sample populations at each position are shown in figure 15.

While the numbers present at the higher levels are too small to permit a good comparison of their size with the size of specimens farther out, the measurements both at the end of the first season when settlement occurred and late in the following summer, fall within the same general size range.

Bottom.

Of the three beds north of the dyke, No.1 was in moderate firm, sandy mud; No.2, in soft mud; No.3, in very soft mud. No difference in growth rate between these beds is apparent, and it may be concluded that the kind of bottom did not influence growth. Inside the dyke, the small number of specimens recovered from very hard gravel bottom on boards (bed 5) makes difficult a comparison of growth between beds 4 and 5. Also, the quahaugs in bed 5 were not normally buried, but sometimes out of the bottom.

Water Circulation.

On September 9th, 1940, two collections of large quahaugs were made in the Basin, (a) from the sandy beach at F (figure 3), and (b) from a channel at C, 3 feet deep and about 10 feet wide. From the appearance of the growth rings, the specimens from the channel appeared to have grown more rapidly, and measurements were made of the heights to the edge of each ring, in 15 specimens of both lots. In table 6 the average heights to the end of several intervals are shown.

Table 6.

Interval	Number of measurements	Sand beach mean height	Channel mean height
End of 2nd year	15	11.3 mm.	12.8 mm.
" 5th "	15	33.2	38.5
" 10th "	15	60.2	63.9
" 12th "	15	74.0	76.2
" 16th "	13	76.4	79.1
" 20th "	7.9	82.5	85.9

Measurements of the currents at the two positions were made by Mr.J.R. Adams, on September 12th, when the tide was half eff. Readings were made only at a distance of 2 feet above bottom at each place with the Gurley current meter, and gave a velocity of 0.46 feet/sec. in the channel as against 0.28 feet /sec. on the beach, while the current at the bottom of the channel was 0.28 feet/sec. The faster rate of growth shown throughout in the above table by specimens from the channel is very likely a result of increased circulation of water there.

General Conclusions.

Temperature and salinity conditions are parallel throughout the growing season in the Tatamagouche bay area and the Bideford river area.

In Tatamagouche bay quahaugs in wide areas of the intertidal zone from low water level to at least half-tide level, do not grow significantly less than quahaugs having complete water coverage. Growth in these areas is similar in extent to growth near and below

low water level in Bideford river, but at the latter location growth near half-tide level is much less than at lower levels. This is a result of greater tidal amplitude in Tatamagouche bay and the lack of prolonged low water periods during the times of diurnal tides, as opposed to conditions in Bideford river.

The growth of quahaugs was not influenced by the kind of bottom.

Faster growth of quahaugs in a channel than on the shore nearby was apparently correlated with greater current over the bottom in the channel.

INVESTIGATION OF FACTORS LIMITING SURVIVAL AND DISTRIBUTION

Preliminary exploration in 1938 gave some information on the distribution of Venus mercenaria in the Malpeque bay area, P.E.I., and in the Tatamagouche bay area, N.S., and suggested a number of factors worthy of investigation as limiting survival. This was followed by experiments and more exploration in 1939, and supplemented by the interviews with fishery officers and quahaug fishermen on the history of the fishery. In 1940 field observations have provided more information on the importance of several factors, such as eel grass and drilling by Polinices heros, limiting survival, and a study of fishery statistics and government reports has shown the probable cause of the decline of the quahaug fishery about 1912 to be overfishing and lack of any attempts at conservation.

The information obtained up to the present time will be presented by considering each probable factor separately, with a view to showing the relative importance of each to the survival of the quahaug.

Salinity.

The most important factor limiting the distribution of quahaugs must be salinity, since they are marine forms, Suitable salinities for their development and growth lie within the range of about 27 to 30 parts per mille, as it is in situations having such salinities that quahaugs occur on the Atlantic coast.

Information on the lower limit of salinity below which quahaugs may not be expected to survive was sought in Bideford river. Here salinities have been taken at intervals throughout the period of open water for several years, at a number of stations from near head of tide to Malpeque bay. At 2001, a station in Paugh's creek, only a few hundred yards from the head of tide, salinities are not much lower than at the mouth of Bideford river, except in the spring, as shown in figure 7. In 1940 there was less fluctuation of bottom salinity at 2001 than in 1939, with a low value of 23.0 per mille on May 17th and an accompanying surface salinity of 7.8 per mille, while salinities over 26.0 per mille occurred on the bottom for the rest of the season, when observations were made.

Dragging the bottom of the three heads of Paugh's creek in September 1939 showed that quahaugs occurred up each one for some distance, as marked on figure 2. They are thus able to survive even lower salinities than those recorded at 2001, since these places are only several hundred yards from head of tide, and it would be expected that the fresh water would not yet be well stratified on top of the salter water following spring floods of fresh water from the land. This location may be considered typical of creeks tributary to inlets or "rivers" entering Malpeque bay, and it may be concluded that there is practically no limit placed upon the distribution of quahaugs in the area by salinity. In other parts of the Atlantic coast region where quahaugs occur, there are greater differences in salinity between the heads of rivers and the river mouths than ever occur in Bideford river as, for example, along the south shore of Northumberland strait where more fresh water is supplied by the rivers. Here it would be expected that quahaugs would be limited to areas near the river mouths where salinities would not average lower than about 20 per mille. 20 per mille is generally considered to be the lower limit that can be survived by oysters for any length of time, and quahaugs and oysters have similar distributions.

In 1939 laboratory experiments were conducted to determine how long quahaugs of various sizes could survive in sea water and dilution of sea water down to fresh water, at temperatures ranging from ordinary summer temperatures around 20°C. to temperatures above those ever recorded over quahaug beds. These experiments are described in detail in the appendix.

In these experiments large quahaugs, 60 mm. in length, lived in fresh water for at least 30 days at a constant temperature of 20°C., for at least 10 days at 30°C., but for less than 1½ hours at 40°C., when placed suddenly in water at these temperatures from a temperature of 20-21°C. on the sea bottom. Quahaugs of average length (8 mm.) lived for a shorter time than larger specimens in lowered salinity, but even in fresh water survived for 3 days at 30°C. When quahaugs were held at 35°C. following a gradual rise to this temperature at the rate of about 1½°C. per hour, small quahaugs survived fresh water for about 5 hours, and one-third sea water, and two-thirds sea water, much longer. During the summer of 1939 the highest temperature recorded in the intertidal zone on Bideford river was 35°C. at low tide in the afternoon of August 14th, at half-tide level. In 1940 the highest temperature occurring at the half-tide level during the summer was 31.1°C., on August 4th, and it is highly improbable that temperatures as high as 35°C. would ever be reached in any situation where significant numbers of quahaugs could occur.

Raising the temperature of the water of various salinities surrounding quahaugs at the rate of 1 to 1½°C. per hour, such as might be experienced in nature, showed that survival in all salinities could be complete after a maximum temperature of 39.6°C. had been reached. There was no appreciable difference in the ability to survive temperature, correlated with salinity. Quahaugs held in sea water with salinity increased to 5/3 and 4/3 normal survived an increase of temperature towards 40°C. as well as specimens did in ordinary sea water.

The ability of quahaugs to withstand reduced salinity for considerable periods of time is doubtless related to the tight closing of their valves for the duration of the exposure. In the laboratory experiments it was only in ordinary sea water that specimens opened and exposed their siphons. Dugal (1939) has shown that the ability of quahaugs to maintain life when closed is related to their use of calcium carbonate from the shells for buffering.

Temperature.

Field observations of temperatures occurring throughout the open water periods of 1938, 1939, and 1940 in situations where quahaugs were living, and laboratory experiments (see appendix) in which specimens were subjected to various temperature conditions have indicated that high temperature in itself is of no significance as a factor limiting the survival of adult quahaugs. The importance of temperature in the early life history has been demonstrated each year, when the minimum temperature for spawning has been several degrees higher than required by the oyster.

(a) Adults.

There was no mortality of specimens due to high temperatures in the experimental plots below half-tide level in Bideford river in any year. The maximum bottom temperatures at the position of the low water beds in 1939 and 1940 are shown in figure 6. In figure 8 are shown the maximum and minimum temperatures at the various 1940 bed positions. The highest temperature recorded at any position has been 35°C. at position 2, during low water in the afternoon of August 14th, 1939.

In the laboratory expermients, small quahaugs of less than 10 mm. length survived high temperatures in sea water for longer periods and had somewhat higher lethal temperatures than had larger specimens of size similar to those held in the experimental plots on the shore. A maximum sub-lethal temperature of 39.9°C. was found for small quahaugs of average length 5 mm. when this temperature was reached at the rate of 1 to 1½°C. per hour. In experiments where quahaugs were raised to temperatures around 40°C. in sea water of high salinity, such as might result from evaporation in tidal pools at low water, survival was as good as in ordinary sea water. The specimens remained closed in these increased salinities.

(b) Spawning.

The importance of temperature in limiting the distribution of bivalve mclluscs is concerned with the spawning of adults, as pointed out by Nelson (1928). He stated that Venus mercenaria is found only in relatively few sheltered areas where subtropical spawning temperatures of 25°C. are attained, while Mytilus edulis, with a low spawning temperature between 10 and 12°C. is the most widely distributed marine lamellibranch in the northern hemisphere.

Observations on the time of appearance of quahaug larvae in Bideford river over three summers have shown that the onset of spawning occurs somewhat later than in the oyster and apparently only after the water temperature over the quahaug beds has reached at least 23°C. For example, in 1938 no larvae were found in plankton tows until June 23rd when a bottom temperature of 23.3°C. occurred; in 1939 a maximum bottom temperature of 27.0°C. occurred on June 29th, before any quantity of larvae appeared, on July 7th; and in 1940 umbo stage larvae were found on July 16th, preceded by a maximum bottom temperature of 26.0°C. on July 10th. In 1939 and 1940 tows were taken regularly at intervals of several days throughout the season over the quahaug beds in Bideford river, and daily following the first appearance of the larvae and for several weeks thereafter so that calculation of the rate of growth might be attempted. The last dates on which any quahaug larvae occurred in the tows were September 11th in 1939, and August 29th in 1940. Reference to the temperature records for these years (figure 6) shows that spawning ceased at about the time temperature of the water at the beds fell to about 15°C. after the period of summer maxima.

Location of settlement.

Reference has already been made to collections of small quahaugs at 50-feet intervals from high water level to low water level on the shore of Tatamagouche bay (at E. figure 3) and to the use of the size-frequency distributions (shown in figure 15) in determining the growth at different positions. The same histograms show the relative abundance of quahaugs at different levels of the intertidal zone.

In both 1939 and 1940, the maximum number of specimens of the previous year's settlement occurred near the half-tide level, and none were found as far out as the low water level. On the shore of Tatamagouche Bay in this location there is no apparent difference in the nature of the bottom from half-tide level outward to the position at which the distribution of small quahaugs ended, the bottom being fine, firm sand. Therefore the suitability of bottom for settlement of quahaugs is not likely to be a factor limiting their distribution here. Experiments at the Prince Edward Island Biological Station have shown that quahaugs of all sizes exhibit no significant horizontal movement, and there is little likelihood of migration toward the half-tide level. The only reasonable conclusion to be drawn is that the maximum settlement of both 1938 and 1939 free-swimming larvae occurred near the half-tide level. Weymouth (1923) describes a similar distribution of young Pismo clams at Oceano beach, California; he considers that the young are found near the half-tide level in maximum numbers because it is the level at which most of the larvae reach the sand, but he can offer no explanation for this occurrence.

In 1939 and 1940 a few quahaugs have settled on experimental concrete-coated oyster collectors which were set out at various distances from the bottom of Bideford river, up to distances of

8 feet. None have been found settled on collectors within 3 feet of the bottom, but some have settled at distances of 3 to 5 feet above bottom. This suggests that the most favourable location for settlement, provided a suitable settling medium is present, is somewhere intermediate between the bottom and surface of the water. If settlement occurred at high tide, the maximum number of larvae would be expected to settle at about the half-tide level, where the layer of settling larvae would come in contact with the bottom. Further work is necessary to prove this point.

The important conclusion to be drawn is that maximum numbers of small quahaugs in the year following settlement can be expected to occur near the half-tide level on the intertidal zone. This is very likely the location where maximum numbers of free-swimming larvae have settled.

Exposure.

In Bideford river the distribution of quahaugs in the intertidal zone is limited to the lower levels by exposure.

Quahaugs planted just above half-tide level in 1939 survived and grew, while just below high water level where there was water coverage for only a few hours or less each day the specimens did not survive for more than two weeks in the summer (figure 10), and died in about the time specimens of the same size died in air in the laboratory experiments. (Appendix 1) After quahaugs have been out of water, there is some lapse of time before the valves reopen upon covering them with water again, and it is probable that the specimens at the upper levels never opened to take in water during their brief opportunity to do so. Examination of the specimens shortly before they died showed that there was little or no fluid in the mantle cavity, and the valves were sometimes held slightly apart by sand grains lodged between their edges. The maximum temperature recorded above the half-tide level during the summer of 1939 was 35°C., and the survival times of quahaugs held at this temperature in the laboratory suggest that death did not result from high temperature.

Evidence of winter killing of small quahaugs in Bideford river near the Biological Station was obtained in 1940. In previous years only a few specimens in their second year could be found by screening the bottom from high water level to beyond low water level, and these were beside stones or near the piles of the landing stage. Following the planting nearby of a large bed of quahaugs for spawning, more larvae appeared in the water during 1939, and in May, 1940, small living quahaugs occurred with a frequency of about 1 per 2 square feet near low water level, where the bottom shelved rather steeply. Between half-tide and low water level, empty shells of the same small size occurred with greater than the above frequency. Such winter killing was probably associated with ice, which breaks up into large cakes at these depths, moves up and down, scrapes against the bottom, and often picks up and encloses such objects as oysters at the surface of the bottom, unless they are protected by large stones nearby.

Therefore, the number of small quahaugs on the shore of Bideford river can be increased by provision of additional stock for spawning, but survival beyond the first winter should not be expected at depths above low water level.

Eel grass.

Observations made in the Basin, Malagash, N.S., in 1939 have indicated the importance of eel grass to the survival of small quahaugs in very soft muddy bottom.

In the period May 31 to June 2, a careful search was made of the very soft bottom along the edge of the channel at position C, (figure 3), Large quahaugs, 6 cm. long and larger, were very abundant but smaller sizes were entirely absent between the channel and the half-tide level. Examination of the shell rings showed that all the specimens were at least 8 years old, and in a collection of 75 specimens the oldest was 17 years. Representatives of later age classes from 2 years of age upward were found several hundred yards eastward at D, along the shore of Clarke's point. These were scattered through rather dense patches of mussels on hard bottom near the half-tide level, and were attached to the mussels by the byssi of the latter. Thus the absence of young quahaugs in the soft bottom at C was not due to failure to spawn in recent years.

Eel grass was very abundant in the Basin at Malagash before 1931-1932, according to local residents, but in those years it disappeared almost completely. Its disappearance is discussed by Dr. Huntsman (1932) and the opinion expressed that the disease was probably in Virginian waters in 1930, being responsible for scarcity of eel grass there in 1931, then spread northward, effecting eel grass as far as Cape Breton island and Northumberland strait in the latter part of 1931. In 1932 it caused great scarcity of eel grass on the north shore of Prince Edward Island and up the east coast of New Brunswick. An unusual circulation of water bringing in tropical forms to our coast may have been responsible, and the exact nature of the disease is unknown. Small quauahgs upon settling out of the water at the end of their free-swimming larval period have the ability to produce a single-thread byssus from a byssal gland located in the foot. The use of the byssus is evidently to enable the small clam to survive for a year or two until it becomes large enough to maintain its position by the foot along. The largest quahaug found with visible byssus was 8.8 mm. long and the byssus was between 10 and 15 mm. long, and very elastic. Such a quahaug will hang suspended by the byssus, or if the byssus is firmly attached to stones and the quahaug is pulled about 5 mm. away from its position on the bottom, the quahaug will return to near its original position when released.

It is very probable that the large quahaugs now living in the soft bottom at Malagash survived after settlement by attaching themselves to the eel grass which was then abundant. In 1939 small specimens, 5 mm. long, were left on sand on the bottom of finger bowls in the laboratory and later they were found hanging several millimetres above the bottom from their byssi, which were attached to the glass above them. On August 19th, 1940, the ability of small newly-settled quahaugs to climb up a surface above bottom was observed. A new larva-rearing jar floating on the surface of the water had been designed to hold bivalve larvae just below the water surface, and quahaug larvae of settling-out size had been picked from plankton tows and placed inside the jar. Two days later a specimen 0.5 mm. long was seen clinging to the glass at a distance of one inch above the bottom, and from here it climbed another half inch. In climbing, the foot extended and attached to the glass, then the foot contracted and the body was drawn to a new position. The quahaug then descended by falling free for about one-third inch and coming to an adrupt stop against the side of the jar, when it began to descend more slowly. Although it was not possible to see a byssus thread, one must have been present to check the fall in this way. No published observations on the climbing of small quahaugs above the bottom have been found. Belding (1912) describes the settlement of larvae on surfaces above bottom but nothing is said about climbing upward after settlement, a point which has considerable importance in that it should allow the small specimens to raise themselves clear of silt, provided a supporting surface is near.

Observations on the occurrence of small quahaugs of the 1939 set were made on July 5th, 1940, between half-tide level and low water level on the south shore of Bideford river near 2007 (figure 2). The river bottom here consists of fine sand which can be screened easily. Patches of eel grass between five and ten feet in diameter, were scattered over the bottom, with clean bottom intervening. To compare the distribution of small quahaugs on clean and grassy bottom, equal areas of bottom were shovelled to a depth of 2 inches in situations at the same level, Each sample of 10 shovelsful contained the following numbers of quahaugs:

Sample	Clean Bottom	Bottom covered with eel grass
1	0	3
2	3	4
3	2	8
4	4	10
5	3	7
Total: 28 sq.feet area	12	32

The number of small quahaugs taken on bottom covered with eel grass was in every case greater than the number taken on the clean bottom nearby. Thus even on a sandy bottom the presence of eel grass favours the survival of small quahaugs, likely by providing support for attachment of their byssi.

Storms.

On November 25th,1938, a very heavy storm occurred on the Atlantic coast. In the Malpeque bay area a very strong east wind was accompanied by an unusually high tide, resulting in considerable disturbance of the bottom in the intertidal zone. In some places the shore line of Bideford river was moved back several feet by wave action.

Examination in May 1939 of quahaug beds established in 1938 along a line running north-easterly from the Biological Station, showed that the beds in the intertidal zone were disarranged and many of the specimens dead. Many specimens were buried under sand up to depths of 6 inches; these were all dead and rotting meats were still present in some. Other shells were at the surface and shreds of meat were attached to some of these also. Raking the bottom at one position near the half-tide level, where 23 specimens had been planted on July 11th, 1938, produced 12 specimens, 6 of which were alive. There was no appreciable disturbance of the beds from just beyond the low water level outward.

Exploration of the intertidal zone at 2007, just west of Port Hill wharf, at low tide on May 24th, 1939, showed the empty shells of large numbers of quahaugs, oysters, razor-clams and other molluscs, scattered over the bottom. There was no abundance of empty shells there in September 1938; they all had a fresh appearance, and it was evident that they had died recently, and as a result of the upturning of the bottom in November, 1938.

On September 16th, 1939, a heavy storm occurred, with wind estimated to be as strong as in November 1938. However, the tide did not rise much above ordinary high water mark, and the wind changed direction before any significant damage was done to quahaugs in the intertidal zone. The only damage was to specimens held on floating trays.

Experiments have shown that quahaugs can regain the surface after burial to several inches, and during the summer, when temperatures are high not much mortality as a result of storms might be expected. During colder weather, when they are hibernating, as in November of 1938, it is very unlikely that quahaugs could regain the surface if buried, and smothering was probably the cause of many of the deaths observed. Or, other specimens may have been left on the surface of the intertidal zone to be picked up by the ice which forms large cakes along Bideford river, and killed by low temperature, as discussed above.

Movement.

Several experiments were set up in 1939 to determine to what extent the distribution and the survival of quahaugs might be affected by their lateral and vertical movement.

(A) Lateral movement.

1. On July 27th, 1939, groups of quahaugs from three size classes, small (15-29 mm. height), Medium (42-50 mm. height) and large (53-74 mm. height) were notched characteristically and set out on the bottom at definite positions in relation to stakes on the shore of Bideford river west of 2003. An interval of one foot was left between each specimen, and two series were set up, one just outside half-tide level on hard sand, the other at low water level on sandy mud, each series consisting of three specimens from each size class.

At both levels a group of seven small specimens (height 28-30 mm.) were planted as close together as possible at marked positions.

Recovery of the specimens was attempted on September 27th at low tide, and most of them were found. All the large specimens were found at the same spot as planted except one at the inner position, which had moved away 3 inches. Of the medium sizes one could not be found at the inner position and others here had not moved; at the outer position all were found, and only one had moved, a distance of 2 inches. Only one of the small sizes was located at the inner position and it was $2\frac{1}{2}$ inches away from its original location, while at the outer position, two of the three specimens were found, one having moved 4 inches, the other 2 inches.

Of the crowded specimens five were located at the inner position, at distance of 3, 5, 12, 12 and 13 inches from the centre of planting. Six of the specimens crowded at the outer position were located, at distances of 1, 2, 5, 6, 7, and 15 inches from the centre of planting.

As only a very short time was available for the search, the failure to recover all the specimens is probably due to all the bottom surrounding the centre of planting not being covered. Searching the bottom at the outer position was easier than at the inner position because the bottom near low water level is softer.

ii. On July 31st, an experiment to determine the movement of quahaugs in very soft bottom and in moderately soft bottom was set up in Paugh's creek at B (figure 2). 200 specimens, (22-82 mm.) characteristically notched, were dropped to the bottom between stakes near the middle of the creek where the bottom is very soft and muddy. A similar lot was dropped to the moderately soft bottom about half way to shore. On September 25th and 26th, Mr. Colin Hutchinson dragged for the specimens and obtained 184 at the outer location and 170 at the inner. Going over the bottom at the two places on the following day, the numbers were raised to 195 at the outer and 185 at the inner position.

The quahaug at the inner position were very closely bunched, while those at the outer position were scattered more, but were inside an area of not more than 8 square feet. The greater spreading was probably due, at least in part, to the quahaugs falling through a much greater depth of water at the outer position when they were put out.

From these experiments and from the fact that specimens planted in numerous beds in 1939 and 1940 have shown no appreciable movement throughout the growing season, it may be concluded that quahaugs in beds with bottoms of any degree of hardness exhibit no significant lateral movement.

(b) Vertical movement.

i. On July 27th, 1939, quahaugs from the same three size classes as in experiment (a) i above were buried at depths of 1 inch, 2 inches, 5 inches and 7 inches just outside the half-tide level, west of 2003. Four small, three medium and 2 large specimens were buried at each depth.

After 24 hours all the specimens had reached the surface. Such ability to regain the surface quickly following burial could be important if quahaugs were covered by shifting of the bottom during storms, provided low spring or autumn temperatures were not prevailing, when the quahaugs would be inactive.

ii. Small quahaugs, averaging 5 mm. in length, were buried to depths of $1\frac{1}{2}$, $\frac{1}{2}$ and 1/8 inches in fine sand in a battery jar, through which sea water was running, in the laboratory, at 10 a.m., July 28, 1939. By 2.45 p.m. all (3) were at the surface from burial to depths of $\frac{1}{2}$ and 1/8 inches, and 1 of 6 buried to a depth of 1½ inches had reached the surface. By 3.10 p.m., 2 more of the last lot were at the surface, and by 9.30 p.m., all had reached the surface. The positions of the various quahaugs were marked by wire pointers from above. After four days there had been no lateral movement of any specimens.

iii. 2 small, 5 mm. long, quahaugs were placed at the bottom of test tubes and covered with (a) soft mud and (b) fine sand, to a depth of 3 inches. The test tubes were placed upright in a battery jar through which sea water was circulsting, at 4 p.m., July 29, 1939. At 7 p.m.,1 specimen in (a) had risen 2 1/8 inches, the other 1 1/4 inches. Neither specimen in (b) could be seen. At 8.30 a.m.,July 30, 1 was 2 5/8 inches from the bottom in (a), and 1 was at the surface in (b). At 7 p.m. both were at the surface in (a), only one was up in (b); the other was dead at the bottom in (b).

These experiments show that even small quahaugs, 5 mm. in length, may regain the surface within 24 hours when buried to a depth of several inches.

Predators.

The gastropod, Polinices heros say, is the only enemy of the quahaug found during the investigation. It was first discovered on the bars in the Basin at Malpeque in 1938, with drilled and empty quahaug shells nearby. In the following year quahaugs were found being drilled and large collections of drilled shells were made. The size of clams that can be attacked successfully by any Polinices appears to be limited, due to the method of attachment of the predator by curling the edges of its large foot around the valves of the quahaug, when the radula is near the umbo of the latter. In 99% of the drilled shells examined, the bevelled hole has been near the umbo. In the Malagash area Polinices, larger than 63.0 mm. in height have never been found, and the largest quahaug ever found drilled was 54.0 mm. in length. In 1939, 5 large (height 47.5-56.0 mm.) and 5 small (height 37.0-41.1 mm.) Polinices were caged in the Basin, by Mr. J.R. Adams, with 15 specimens of Venus mercenaria of various sizes. At the end of two weeks the five smallest quahaugs with heights, 25.7 - 33.6 mm. had been drilled but 10 larger specimens, 46.0 to 69.0 mm. in height, were still alive.

Drilling by Polinices heros has been found to be largely responsible for the absence of small quahaugs in the Basin, at Malagash, and on the shore of Tatamagouche bay. In August, 1939, screening the bottom on the west shore of Tatamagouche bay showed quahaugs spawned in 1938 to be distributed on an average of 5 per square foot near the half-tide level where maximum numbers occurred (figure 15). On September 21st, 1939, a collection at the same location showed that many of the 1938 quahaugs had been drilled. On May 22, 1940, extensive screening at the same position showed the complete absence of living 1938 stock, but large numbers of drilled shells of this size-class were found washed up along the high water mark. Small quahaugs spawned in 1939 were found in screenings on September 6, 1940, but the number of living specimens was very small, while the number drilled was high as shown in figure 15.

The size-frequency distributions of both the drilled and living 1939 set of quahaugs at the various positions have been determined by measurement of the first growth ring and the final size. A similar distribution on the shore to that found for the 1938 set in 1939 was found, with maximum numbers occurring at positions between 500 and 750 feet from high water mark, or just beyond the half-tide level. Small quahaugs were found higher up on the beach than in 1939, and these had all survived, when not more than 150 feet from high water mark. The bottom was hard sand and gravel here and no Polinices were found.

The failure of sets of quahaugs to survive in recent years in the Tatamagouche bay area can be attributed to drilling of almost all small quahaugs by Polinices heros. Over 80% of all dead quahaugs collected were drilled.

In the Malpeque bay area, Polinices heros does not occur in very large numbers in places where quahaugs occur. Very large specimens have been found near the gulf of St. Lawrence, and large numbers of other species of molluscs have been found drilled and washed up along the high water mark here. Occasional specimens of Polinices heros have been found at D (figure 2), but only a very small number of small quahaugs have been found drilled here. No quahaugs were drilled in any of the experimental plots near the Biological Station until 1940, when three in one bed ware killed in this way.

Disease.

No direct observations were made on supposedly diseased quahaugs until September 3, 1940,when considerable numbers of shells of small quahaugs in their fourth and fifth years were found at the surface of the bottom of Enmore river, P.E.I. (figure 1). Along with the empty shells were some living quahaugs similarly situated at the surface, and one specimen, just dying, was found, with the valves slightly agape and emitting an unpleasant odour.

A collection of 193 empty shells was made in an area of several hundred square yards. Their lengths ranged from 14.8 to 36.4 mm., and the growth of shell in 1940 was very little in comparison with growth in previous years. For example, from the start of the 1940 growing season until September 3rd, when most of the seasons growth is completed, the smaller specimens had grown an average 0.5 mm. in height as compared to 9.0 mm. in the 1939 growing season. The larger specimens had grown about 2.0 mm. in height, as compared to 9.0 mm. in the previous year.

Six living specimens exhibited the same slight growth in 1940. They ranged in length from 25.7 to 31.0 mm. in length, and their growth in 1940 varied between 0.5 and 3.0 mm. as compared to increase in height of 6.8 to 9.7 mm. in 1939. One specimen in weakened condition and obviously dying was found. It was 26 mm. long, and showed only 0.9 mm. growth in 1940.

Examination of the meats of the 6 living specimens failed to show any unusual characteristics sometimes reported in supposedly diseased bivalves, such as spots or unusual colouration. Slow growth during the season preceding death of oysters by disease has been observed by Dr. A.B. Needler, and the death of quahaugs following very slow growth was also very likely a result of disease. Disease in oysters has occurred during the past several years in Enmore river, while there has been no indication of its presence.

on the north shore of Prince Edward Island, in the Malpeque bay area since 1916.

Disease in quahaugs in Nova Scotia was reported in 1940 by Mr. Roy Weatherbie, who operates a cannery at Brule Point on Amet sound. He described the opening of the valves and the apparent death of quahaugs which had been piled on the beach after fishing and left for several hours in sunlight before being taken into the cannery. This was thought to be a result of disease, which he said caused considerable numbers of dead and dying quahaugs to occur from time to time in localized areas.

Piles of quahaugs have been left near shore in Bideford river for days, during the hottest part of the summer in 1939 and 1940, and no mortality has resulted. However, experiments were preformed at the Biological Station at the end of the summer in 1940 to determine the effect on quahaugs of exposure to the sun and air.

Experiment 1.

On August 29th, 50 quahaugs of various sizes were placed inside an insulated box, open at the top, and situated to receive direct light of the sun throughout the afternoon. By 2.40 p.m., a temperature of 81°F. was read on a thremometer placed beside the specimens. After three days in the box all the specimens were alive, but on August 30th and 31st the sky was partly cloudy and high temperatures were not reached.

Experiment 2.

The insulated box was provided with a glass cover, and 100 quahaugs of medium and large size fished in Bideford river, were placed inside on September 2nd. The specimens were piled about ten deep, and a maximum and minimum thermometer was placed beside the specimens in the upper layer. The maximum temperatures recorded in the box over several days, with the sky conditions at midday were as follows:

Date	Maximum temperature reached	Sky
Sept. 20	106°F.	Clear
21	118	Clear
22	66	Dull
23	108	Clear
24	118	Clear

None of the specimens died. Several on the surface were open 1 to 2 mm. when the temperature was high and they lost a few drops of shell liquor at this time. In the evening, when the temperature fell, all specimens closed tightly.

The experiment shows that very high temperatures can be survived by quahaugs from Bideford river, even when exposed to the air. It would appear that the quahaugs which died at Brule Point, were suffering from some unusual condition, possibly the so-called "disease", the nature of which is not known.

In 1914, large numbers of quahaugs, supposed to be suffering from disease, died in shipment from Buctouche, N.B. to Chicago. The greatest losses, amounting to from 13 to 60% of shipments ranging from 15,000 to 65,000 specimens, occurred from June 10th to July 8th. An investigation of the causes of death was attempted by Dr. Phillip Cox (1916), who was unable, by microscopic examination of the fluid and organs of many specimens, to find any trace of disease due to pathological causes. Several experiments suggested that the losses could be accounted for by the manner of storing quahaugs before and during shipment, when there was little consideration given to crowding and temperature variation.

In the light of later evidence of disease in quahaugs, it appears probable that the clams referred to by Cox were suffering from a weakened condition, which he seemed to doubt, making them unusually susceptible to crowding and temperature variations.

Rate of Growth

Before June 1st, 1939, collections of 100 quahaugs were made in Paugh's creek (B, figure 2) and in Bideford river near Port Hill wharf (E, figure 2). Measurements were taken with vernier calipers of the height of the shell to the end of each year's growth, beginning at the second year, and these have been grouped into classes of 2 mm. height range. Height-frequency polygons have been constructed to show the distribution of size at the end of each year. These polygons have been plotted along the ordinates corresponding to the various years, and when the medians of each distribution are joined, the age-size relationships at each location are obtained, as shown in figure 17.

Plotting the data in this manner shows the variation in height at the end of each year, and the range of time within which quahaugs may be expected to reach a particular size can be readily seen. For example, to determine the time required to reach marketable size, a line has been drawn at the height corresponding to the minimum marketable length of 1¾ inches (determined from the height-length relationship, figure 18). It is then clear that at Port Hill wharf, quahaugs reach marketable size in from 4 to 7 years, while in Paugh's creek 6 to 9 years are required to attain the same size.

The growth rate of quahaugs is slow as compared to that of oysters, which can reach marketable length of $3\frac{1}{2}$ inches in 3 or 4 years. This difference in growth rate has not been appreciated by oyster and quahaug fishermen, and is probably the reason for the severe overfishing of quahaugs which has occurred in the past. This will be discussed further in the following section.

Rate of Removal

There have been two sources of information on the extent of quahaug fishing in the past and its effect on the survival of quahaugs; first, yearly statistics and reports of fishery officers, published by the government of Canada, and second, quahaug fishermen and fishery officers who have been interviewed.

(a) Fishery Statistics and Reports.

Usually a complete history of the fishery of any commercially-important species can be obtained from the Annual Fishery Statistics published by the Canadian government, but this has not been possible in the case of the quahaug. Probably because the value of both the soft-shell clam (Mya arenaria) and the quahaug fisheries have been low for considerable periods of time, the catches of both species have been combined frequently. Since 1935, separate listings have been given for quahaugs in each province, but before this time catches of quahaugs were always combined with clam catches in Nova Scotia, and separate catches of quahaugs in New Brunswick were listed only from 1911 to 1914. Fortunately, more complete data have been given for Prince Edward Island, where quahaugs were listed separately from 1905 until 1914. This interval evidently covers the only time when quahaugs have been fished intensively on Prince Edward Island, as previous to 1905 the combined figures for clams and quahaugs were low, fluctuating around 1000 barrels per year, and after 1914 there was little fishing.

The total annual catches of quahaugs in Prince Edward Island and the annual catches in the Malpeque bay area alone are shown graphically in figure 16. The percentage of the total Prince Edward Island catch coming from the Malpeque bay area increased from 24% in 1906 to 49% in 1907, and 1913 it had reached 92% of the total catch. Thus the relative importance of the Malpeque bay fishery was large during the boom years, and a consideration of this area along should be sufficient to show what significant conditions existed in general.

The great increase in the catch of quahaugs in 1906 and 1907 was a result of a market opening in the United States, according to the report of Inspector Matheson of District No.2, Prince Edward Island, in 1906. The marketed value of quahaugs from all Prince Edward Island in these two years is listed at $95,424.00 and $96,572.00 respectively. The catch fell off very considerably in 1908 and Inspector Matheson suggested that "this industry is becoming exhausted". The slight increase in 1909 was attributed to greater activity of fishermen, and he warned that "in a very short time quahaug fishing will be a thing of the past". In 1911, following the peak of 1910, Inspector Matheson reported that "the quahaugs are getting scarce and being fished out". "Fishermen can scarcely make a fair day's wage at the work. Our American neighbours are importing quahaugs for the purpose of cultivation of their own waters and our public beds are becoming depleted."

This importation of quahaugs into the United States was referred to by Belding (1912) when he suggested that small quahaugs could be obtained from Prince Edward Island to stock areas in Massachusetts, where a set did not occur naturally. In another instance he wrote "at the present time (1912) a considerable number of small quahaugs of peculiar color, shape and flavour are shipped from Prince Edward Island".

Following another increase in fishing in 1913, the catch was extremely low in 1914. This was attributed by D. Morrison, a new fishery inspector, to the market value being low. There can be no doubt, however, considering the slow growth of the quahaug, and the fact that the smaller sizes were most desired and brought better prices, that overfishing had, by 1914, reduced the quahaug populations on the beds to a very low ebb.

(b) Personal interviews.

Interviews with quahaug fishermen and fishery officers on the past history of quahaug fishing in the Malpeque bay areas are outlined in Appendix 3. The description by Mr. Colin Hutchinson of the large numbers obtained daily by numerous expert fishermen who knew nothing about the rate of growth and age of their catches, is enlightening. It corroborates the report of overfishing made by Inspector Matheson in the government reports referred to above.

It may be concluded that the marked reduction in abundance of quahaugs in the Malpeque bay area around 1912, was largely due to the rate of removal being too rapid, and in excess of the rate of production and rate of growth of quahaugs.

Breeding stock.

For the rate of production of quahaugs to keep pace with the rate of removal of fishing, predators and other causes, it is important that an adequate supply of breeding stock be available. While the number of eggs and sperms produced by one individual may be enormous, as can readily be seen by examination of the gonads of ripe specimens, successful fertilization of only a small proportion of the eggs can be expected. Also, the young quahaugs must lead a hazardous existence during the free-swimming period when they are members of the plankton.

Careful searching of the bottom of Bideford river for small quahaugs in 1938 showed that they were very scarce everywhere but near Port Hill wharf (E. figure 2), where specimens in their second year of life were distributed near the half-tide level, with a frequency of about 1 per square foot. Nearby, large quahaugs were more abundant than at any other place in the river. Up-river, near the Biological Station, large quahaugs were scarce, but small numbers of larvae were identified in the 1938 plankton tows.

In May 1939, a bed of several hundred medium to large sized quahaugs was planted just beyond low water level east of the landing stage of the Biological Station. During the summer, plankton tows were taken regularly over this bed, and a great increase was observed in the number of quahaug larvae over the number present in 1938. Screening the nearby bottom in May, 1940, showed that small living quahaugs were distributed near the low water level with a frequency estimated at 1 per square foot, while inshore, as described above, many empty shells of the same age-class were found. In the two previous years no dead small quahaugs were ever found near this location, only two small quahaugs in their second year of life were found in 1938 after extensive screening along several hundred yards of shore.

Reference has been made (p.8) to the spawning of Venus mercenaria at Milford, Conn.,as males during the first season of growth and as either sex, beginning in the second season (Loosanoff 1937A). To determine accurately the onset of sexual maturity, Loosanoff found that it was necessary to examine seriel sections of hundreds of small quahaugs.

While it has been impossible as yet to make such intensive histoligical studies on Bideford river quahaugs, several observations in 1940 have indicated that quahaugs also mature at an early age in Canadian waters. At monthly intervals, collections of small quahaugs were made near Port Hill wharf (E. figure 2), and smears of the body tissue in the region of the gonad were examined microscopically. On July 15th, active spermatozoa were found in several specimens which were in the second year, but ova could not be identified with certainty in any specimens. However, smears from quahaugs in their third year and older, showed either ova (apparently mature) or active spermatozoa, and there seemed to be equal numbers of male and female quahaugs. Therefore, quahaugs in Bideford river can reach maturity at least by the third year, and males may mature in their second year.

It may be concluded that the present distribution of quahaugs in Bideford river is limited to a great extent by scarcity of breeding stock. Owing to the early age at which quahaugs reach sexual maturity this scarcity should be quickly overcome, if increased numbers of small stock could once be established.

SUMMARY

Studies of Venus mercenaria have been made in Bideford river, P.E.I. and Tatamagouche bay, N.S., locations which are typical of quahaug-producing areas in Canada.

It has been proved that the age of quahaugs can be determined by counting growth rings, and the rate of growth can be calculated by measurement of the shell height to the edge of yearly rings. By this method the growth rate of quahaugs from different localities can be compared.

To determine the effect of various environmental factors on the growth of quahaugs in a particular location, special methods of holding samples in beds and trays have been developed.

There is no evidence that salinity limits the growth of quahaugs throughout Bideford river beds. Following spring thaws and autumn rains, marked vairations in salinity may occur between the head of tide and the entrance of the river into Malpeque bay, but during the greater part of the growing season fluctuations in salinity throughout Bideford river are usually slight. Salinities in the Tatamagouche bay area are very similar to those in Bideford river.

The growing season of quahaugs in Bideford river is short, being delimited by a minimum bottom temperature of about 10°C. Generally there is no growth before June 1st, and little, if any, occurs after September 15th. In the Tatamagouche bay area, the growing season is of similar duration, the temperatures being parallel to those in Bideford river. The growth rate during the growing season is not controlled by temperature alone.

Light has been shown to have no significant effect on the growth rate or shape of quahaugs.

In Bideford river the area suitable for good growth of quahaugs above low water level is very small. This is a result of small tidal amplitude (averaging about 3 feet) and prolonged exposures of the narrow intertidal zone at low spring tides. In Tatamagouche bay the tidal amplitude averages about 8 feet, exposures at low spring tides are much shorter than in Bideford river, and good growth can occur over wide areas of the extensive intertidal zone.

Observations in Bideford river have indicated that growth beyond low water level is not influenced by the depth of water over quahaugs, up to 10 feet.

The kind of bottom in which quahaugs were found has no significant effect on their rate of growth.

The growth rate is much reduced where eel grass occurs on the quahaug beds, and appreciably reduced by eel grass near but not actually on the beds. However, eel grass may favour the settlement of the young.

The growth rate is proportional to the amount of water circulation over the beds. Water circulation is probably the most important factor determining the more rapid growth in downriver locations than in locations near the head of tide in Bideford river.

Crowding of quahaugs when they are planted in beds in Bideford river does not influence their growth rate, but quahaugs which have been crowded into wire containers and held above bottom, grow very little.

In Bideford river there is no significant limiting of the distribution of settled quahaugs by salinity and temperature, and they may occur to within a few hundred yards of the head of tide in the inlets. Laboratory experiments have shown that quahaugs can survive exposure to sea water of lowered salinity and even to fresh water for days at ordinary summer temperatures. The highest temperature recorded during 1939 and 1940 in the intertidal zone of Bideford river was 35°C. in August 1939, and quahaugs survived this temperature in the laboratory for at least eight hours in fresh water and for twenty-five hours in sea water. The maximum temperature that quahaugs of various sizes can survive, when subjected to temperature increase at the rate of 1 to 1½°C. per hour, is between 39.5 and 40.0°C.

Larger sizes are affected by high temperature sooner than smaller sizes, while the smaller sizes appear to be affected by lowered salinity sooner than larger sizes. Quahaugs survived high temperatures in increased salinity as well as in ordinary sea water.

The distribution of small quahaugs, as shown by observations on the shore of Tatamagouche bay, appears to be determined by the location of settlement of the larvae. A few occur just below high water level, and the number increases to a maximum near half-tide level; further out, there is a sudden falling off in the abundance of small quahaugs, and none have been found as far out as low water level.

The general distribution of quahaugs is limited by the temperature which must be reached before spawning will occur. In 1938, 1939 and 1940, spawning did not begin in Bideford river until a temperature of at least 23°C. had been reached. Spawning continued until about September 1st, as a gradual process.

On the shore of Tatamagouche bay, exposure appears to have no importance in limiting the distribution of small quahaugs,after they have settled, since there was no evidence of mortality, except as a result of drilling, in collections made to within 100 feet of high water level.

In Bideford river, while quahaugs can survive exposure to air in summer for at least 60% of the time, and thus inhabit the intertidal zone from low water to above the half-tide level, their survival over the winter is hazardous, in any part of the intertidal zone.

Evidence has been obtained that the presence of eel grass favours the establishment and survival of young quahaugs on very soft bottom following settlement.

Storms of unusual intensity, during cold weather, may result in the death of many quahaugs in the intertidal zone, This is probably a result of the quahaugs being in the hibernating condition and unable to regain the surface if they have been buried, or to bury themselves if they have been exposed.

During warm weather, quahaugs can regain the surface if they are buried to a depth of several inches below their normal position in the bottom, but they are very inactive insofar as horizontal movement is concerned. It is very improbable that the distribution of quahaugs could be influenced by migration.

Very high mortality of small quahaugs on the shore of Tatamagouche bay results from drilling by Polinices heros, the only predator found here. In one location all the 1939 settlement at the position of maximum settlement was killed by drilling, and only those on hard bottom near high water level survived until September, 1940. At the present time there is no serious loss of quahaugs in Bideford river as a result of drilling, although Polinices heros occurs in downriver locations.

Disease among quahaugs has been reported frequently. For example, large numbers of quahaugs died, in Malpeque bay, apparently as a result of the disease, in 1915. In 1940, disease was reported in Nova Scotia. Also in 1940, collections of quahaugs, appareltly diseased, were made in Percival river, P.E.I. There have been no reports of quahaugs suffering from disease in Bideford river and Malpeque bay since 1915.

The rate of growth of quahaugs is slow, 5 or 6 years being required for the minimum marketable length of 1¾ inches to be reached in most favourable locations. This slow growth was not appreciated in the past, and a marked reduction around 1912 in the abundance of quahaugs in many areas can be attributed to the rate of removal by fishermen being in excess of the rate of production

duction and growth.

Observation of increased numbers of small quahaugs in Bideford river, following the provision of increased numbers of large specimens nearby, has indicated that the present distribution of quahaugs is limited to a considerable extent by the scarcity of breeding stock.

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Appendix 1.

TEMPERATURE AND SALINITY SURVIVAL EXPERIMENTS

During the summer of 1939 several experiments were conducted at the P.E.I. Biological Station with the purpose of determining the effect of varying temperature and salinity on survival of quahaugs of different sizes. Small quahaugs in their second year of growth were obtained for the experiments at Malagash, N.S., and held in finger bowls on the sea bottom at Ellerslie until ready for use. Medium and large sizes were obtained at Ellerslie and held on the sea bottom in crates until needed. Three constant temperature cabinets, each consisting of a well-insulated box with a tray of galvanized iron, supported inside so that free circulation could occur around it, were available for the experiments. Finger bowls or other containers for specimens were placed in the tray and surrounded by water. The temperature of the cabinet was maintained by an electric light bulb, controlled by a thermostat, the bulb being situated at one side of the cabinet and separated from the water tray by an air space and screen of corrugated paper.

Experiment 1. To determine the survival times of large, medium, and small quahaugs, in sea water and dilutions of sea water to fresh water, and in air, at three different temperatures, 20°C., 30°C., and 40°C.

Small quahaugs ranging in length from 71 to 92 mm., medium sizes 31 to 36 mm. long and large quahaugs 58 to 64 mm. long, which had been held on the sea bottom at temperatures of 21 to 22°C. were used.

On August 4th, sets of specimens consisting of one from each size class were placed in finger bowls containing 210 cc. sea water, 2/3 sea water, 1/3 sea water and fresh water, in thermostats at 20, 30, and 40°C. One set was exposed to the air in each temperature cabinet. The fresh water was obtained from the well at the Biological Station, and this was used in making up the dilutions of sea water. Observations on the condition of the specimens were made at intervals. The criterion for death was opening of the shell valves and failure to remain closed when pressed together. The thermostats were kept in different parts of the Biological Station to facilitate the maintenance of the various temperatures; the 40°C. cabinet being in the upstairs laboratory, the 30°C. cabinet in the basement, and the 20°C. cabinet in the sub-basement. So situated, the temperatures of each cabinet remained constant to within one degree C. Where specimens continued to live after several days, the water in the finger bowls was changed at intervals of four or five days.

The survival times observed are as follows:

Sea water	L.	Alive after 90 days	12 days	Less than 80 min.
	M.	"	13 "	"
	S.	"	13 "	3 to 6 hours
2/3 sea water	L.	"	10 "	Less than 80 min.
	M.	"	28 "	"
	S.	"	Alive after 54 days	$1\frac{1}{2}$ to 3 hrs.
1/3 sea water	L.	39 days	10 days	Less than 80 min.
	M.	20 days	10 "	"
	S.	10 "	9 "	$1\frac{1}{2}$ to 3 hrs.
Fresh water	L.	30 "	8 "	Less than 80 min.
	M.	39 "	10 "	"
	S.	7 "	3 "	$1\frac{1}{2}$ to 3 hrs.
Air	L.	15 "	12 "	6 to 16 hrs.
	M.	24 "	13 "	"
	S.	Alive at 60 days	20 "	Alive after 26 hrs.

Experiment 2. To determine the maximum temperature that can be survived by quahaugs in sea water, sea water diluted with fresh water, and fresh water alone, following a temperature rise of 1 to 1½°C. per hour above the temperature on the sea bottom.

(a) Preliminary experiment.

On August 13th, 1940, 5 small (length 4-5 mm.) and 1 larger (length 10 mm.) quahaugs were placed in each of 4 finger bowls containing sea water, 2/3 sea water, 1/3 sea water and fresh water, in a thermostat cabinet. The salinity of the sea water was 28.6 per mille. From an initial temperature of 22°C. to 23°C. at the sea bottom, the temperature of the solutions surrounding the specimens was raised at the rate of 1 to 1½°C. per hour.

The temperature of the water in the fingerbowls was 23.0°C. at 9.30 a.m. when the experiment was started. By 8.30 p.m. the temperature was 39.5°C. and from 9 p.m. to 9.25 p.m. a temperature of 39.6°C. was maintained. At this time many specimens in all the finger bowls were open slightly, and those which were closed could be pulled apart easily, for a short distance. The heating bulb was turned off and the specimens were allowed to cool. At 10.40 p.m. running sea water was directed through the bowls.

At 10 a.m. August 14th all the specimens held in fresh water during the experiment were dead, 2 small ones in the 1/3 sea water bowl were closed and resisted opening, and the rest were dead. All in the 2/3 sea water bowl were dead, and 3 small ones in the sea bowl were closed and resisted opening. Sea water was left running over the closed specimens.

On August 15th the only closed specimens were two in the sea water bowl. These were placed in a dish of sea water with an inch of sand over the bottom. On August 15th one of the quahaugs had buried itself, while the other was still on the surface of the sand, but its valves were slightly apart and the siphons were extended. These were drawn in and the valves closed when touched.

(b) Repetition with more specimens.

On September 15th, 25 small (length 4-5 mm.) and 5 medium sized (length 20-25 mm.) quahaugs were placed in each of 4 finger bowls containing sea water, 2/3 sea water, 1/3 sea water and fresh water as before. The salinity of the sea water was 28.8 parts per mille. The temperature was raised at the rate of 1 to 1½°C. from an initial temperature of 16 to 18°C. When the critical temperature suggested by the preliminary experiment was neared, samples were removed at intervals and allowed to cool. Observations made throughout the experiment were as follows:

At 6.15 a.m. the specimens were transferred from sea water at 17.5°C. to finger bowls in the cabinet at 20.0°C. By 4.05 p.m., a temperature of 33.0°C. was reached; all specimens in the sea water bowl had their siphons out while the specimens in the other bowls were tightly closed. A sample of 3 small and 1 medium sized specimens was removed from each bowl to sea water at the same temperature and allowed to cool.

At 7.50 p.m. the temperature was 35.0°C. All the specimens were closed except one in the sea water bowl.

At 8.55 p.m. the temperature was 36.8°C. and another sample of 4 specimens was removed from each bowl.

At 10.30 p.m. the temperature was 38.0°C. and a third sample of 4 specimens was removed.

At 11.50 p.m. a temperature of 38.6°C. was reached. Examination showed that the condition of the quahaugs was similar to that in the preliminary experiment at this temperature. The medium sized specimens could be pulled apart about ½ mm., offering no resistance this far. In a few specimens the valves could not be moved. All the specimens were placed in sea water of 39.)°C. and allowed to cool. At 12.26 a.m. the medium sized quahaugs in the sea water bowl were all closed, and those in the other bowls closed up and remained closed when squeezed. No difference in the condition of the small specimens could be seen.

At 9.30 a.m., September 16th, all the small quahaugs that had been raised to 39.6°C. seemed to have recovered as they had all closed up tightly.

At 9 a.m. September 17th, all the small quahaugs were alive, as their siphons were extended, and they closed when disturbed. The medium sized specimens were also alive.

Observations on the condition of the samples removed at different temperatures were made following their remova;. In every case all the quahaugs survived. Those from the sea water bowl always began to recover first, extending their feet and siphons within 15 minutes. Those from 2/3 and 1/3 sea water behaved similarly showing activity in 15 to 20 minutes, while the specimens from the fresh water bowl did not begin to open for 25 to 30 minutes, except for one specimen taken out at 38°C. which had its siphons extended 10 minutes after remova;. Of the specimens removed at 38°C. the largest of the three small quahaugs from the fresh water and 1/3 sea water bowls were the first to recover.

Experiment 3. To determine the survival times of medium and small sized quahaugs at 35°C. reached by raising the temperature at a rate of 1 to 1½°C. from the temperature at the sea bottom.

On September 26th at 9.15 p.m., 8 small quahaugs (length 6 to 10 mm.) and 3 medium sized quahaugs (length 30-40 mm.) were placed in finger bowls containing sea water, 2/3 sea water, 1/3 sea water and fresh water at a temperature of 18°C., in a cabinet adjusted to give a temperature increase at the rate of 1 to 1½°C. per hour. At 2.10 p.m., September 27th, the temperature was 35°C. Observations on the condition of the quahaugs after this temperature was reached and maintained are summarized in the following table.

Time				
0 Hrs.	Siphons out	Closed	Closed	Closed
8 "	All alive	All alive	All alive	All alive
16 "			1 small dead	2 medium dead
20 "		1 small weak		1 " weak 8 small dead
25 "			3 medium dead	3 medium weak 6 small dead 2 " weak
28 "	1 medium dead 0 small dead	1 medium dead 1 small dead	2 medium dead 3 small dead	3 medium dead 6 small dead

Experiment 4. To compare the ability of quahaugs to survive high temperature in water of salinity greater and less than the ordinary salinity of Bideford river.

Measured quantities of sea water were evaporated to dryness and the resulting salt added to 210 cc. samples of sea water, giving concentrations of 5/3 and 4/3 the ordinary salinity of Bideford river (29.0 per mille in this experiment). 10 small (length 5-10 mm.) and 2 medium sized (length 32 to 36 mm.) quahaugs taken from the sea bottom at 14.5°C. were placed in finger bowls containing 5/3 sea water, 4/3 sea water, sea water and fresh water at 9.30 a.m. September 29th. The temperature was raised at the rate of 4°C. per hour until 40°C. was reached at 3.10 p.m. This temperature was maintained to within 1°C. for several hours, and the condition of the specimens was examined at intervals.

At 3.15 p.m. 1 medium and 3 small sized quahaugs were removed to the air and allowed to cool. When removed they were all slightly open and the valves could be moved apart or closed for a short distance with no resistance. In a short time they were all closed and seem to have recovered. They were returned to the finger bowls in the cabinet.

At 5 p.m. another sample of 4 specimens was removed from each finger bowl. They were placed in sea water at 35°C. and allowed to cool. When removed the quahaugs were all slightly open, while the medium sized specimen from the fresh water bowl had its siphons extended in a limp condition. At 9.00 a.m. September 30th, all the specimens from 5/3 sea water, the 4/3 sea water and the sea water bowls had recovered, but the medium sized specimen and the largest of the 3 small specimens from the fresh water bowl were dead.

At 8 p.m. September 29th, after 5 hours at 39-40°C. the finger bowls were all removed from the cabinet and allowed to cool. Examined at 9 a.m. on September 29th, the only specimens dead were all the small quahaugs held in fresh water at 40°C., the medium sized quahaugs held in fresh water having recovered.

During the increase of temperature to 40°C. on September 29th, all the specimens except those in sea water remained closed until a temperature of 38°C. was reached, when they began to open in all the salinities. Thus when quahaugs are exposed to unusually high or unusually low salinities they remain closed at moderate temperatures. At exceptionally high temperatures, quahaugs in high salinities can survive as well as quahaugs in normal salinity, while quahaugs in fresh water cannot survive as long an exposure to high temperature.

APPENDIX 2.

Growth of Mixed Sizes of Quahaugs at Malagash, N.S. and Bideford river, P. E. I.

Malagash basin. The location of the plots is shown in figure 3.

Size Class	25 - 35 mm. Mean initial ht.mm.	No.	Mean Ht. increase mm.	35 - 45 mm. Mean initial Ht. mm.	No.	Mean Ht. incr. ease mm.	45 - 55 mm. Mean initial Ht. mm.	No.	Mean Ht. increase mm.	55 - 65 mm. Mean initial Ht. mm.	No.	Mean Ht. increase mm.	65 - 75 mm. Mean initial Ht. mm.	No.	Mean Ht. increase mm.
Bed North of Dyke 1. Inner	32.3	3	7.1	40.4	9	8.2	48.9	3	6.1	61.8	14	3.2	66.6	9	2.6
2. Middle	34.1	1	7.0	39.6	11	8.5	51.0	4	5.2	59.5	6	3.0	73.0	1	2.9
3. Outer				39.2	6	9.3	51.3	2	6.0	60.3	14	3.7	67.9	11	3.3
Inside Dyke 4. Soft Bottom	30.3	11	9.6	40.8	10	8.0	50.6	15	5.7	56.9	4	3.9			
5. Hard Bottom				40.9	4	7.2	49.3	4	5.4						

Bideford river. The location of the plots is shown in figure 4.

Size Class	25 - 35 mm. Mean initial Ht. mm.	No.	Mean Ht. incr. ease mm.	35 - 45 mm. Mean initial Ht. mm.	No.	Mean Ht. increase mm.	45 - 55 mm. Mean Initial Ht. mm.	No.	Mean Ht. increase mm.	55 - 65 mm. Mean initial Ht. mm.	No.	Mean Ht. increase mm.	Mean initial Ht. mm.	No.	Mean Ht. increase mm.
2. Bed. half-tide	29.4	8	3.9	40.0	7	1.5	51.8	4	1.2	59.2	12	0.7	70.7	5	0.3
3. ½T bed	30.6	8	8.5	40.3	11	7.3	49.5	10	5.8	58.9	8	2.9	69.2	7	1.8
4. LW bed	32.0	8	10.2	39.0	9	7.8	49.8	8	5.8	59.7	11	3.9	67.8	5	2.6
5. LW sand tray	31.6	9	10.7	37.5	8	10.3	50.6	8	6.0	58.8	9	4.3	68.8	7	2.8
6. LW mud tray	31.5	9	11.5	40.0	10	9.3	52.2	8	6.6	59.7	9	4.0	69.1	5	3.4
7. 5' LW tray	30.3	8	10.1	39.5	10	7.5	51.2	10	3.7	60.2	12	2.6	69.6	5	1.5
8. 10' LW tray	30.4	8	9.1	39.6	10	7.6	50.8	9	4.6	60.0	10	2.9	68.1	5	1.8

Appendix 3.

PERSONAL INTERVIEWS ON THE PAST HISTORY OF QUAHAUGS:

Mr. Colin Hutchinson, who fished quahaugs extensively before their decline, in an interview on July 24th, 1939, stated that quahaugs were found in considerable numbers along both shores of Bideford river, and described fishing them east of Lennox island, south of Bird island, off the Cooper bed (2007), off Maclean's point, and along the south shore of the river between Maclean's point and Low point. Most of the fishing was done along the outer edges of oyster beds, where the bottom was intermediate between very hard sand and very soft mud of a type called "rubber bottom", While some quahaugs did occur in the very soft bottom in the middle of the river and creeks, not many were ever found there, and those from harder bottom were preferred due to the lighter colour of the shell. In Malpeque bay most of the fishing was done east of Curtain island where a channel ran towards Shipyard river, and north of this location along the shore east from Princetown. In these situations the specimens came up clean on the rake, from which it may be inferred that they were living in clean, rather losse sand. The greatest demand was for small quahaugs of length 1½ to 2 inches, called "little necks", andthese were fished in great quantities, bringing one dollar per bushel. A good fisherman could get 3 or 4 bushels in a day.Just before the oyster disease became apparent in 1913, when oysters began to die in large numbers, the price of quahaugs decreased, and so did the fishing. Shortly after, quahaugs began to die also, evidently from a disease, because in places where quahaugs had not been fished out, large numbers were found dead with rotting meats. Quahaugs which had just opened had swollen dark spots on the meats, as if a lighted match had been applied to them.

Mr. V. Carr, fisheries inspector, described on September 26th, 1939, quahaug fishing in the vicinity of Grand river, and corroborated Mr. Hutchinson's description of extensive fishing east of Curtain island. Much fishing was also done on a "reef bed" between Curtain island and Winchester's cape. In Grand river there was good fishing between the ferry and Grand river bridge further upstream, in muddy bottom similar to that in the middle of Bideford river. There were many quahaugs all over the southern part of Malpeque bay before 1915, when large quantities with rotting meats were fished. Specimens obtained from the upper reaches of the rivers in muddy bottom were larger in size than those from sandy bottom in the bay, according to Mr. Carr. (This may be due to the greater area of soft muddy bottom than of harder sandy bottom of suitable depth for quahaug fishing, which, coupled with the greater ease of fishing in the harder sloping edges of oyster beds, served to protect the stock in soft bottom and allowed it to reach a greater age).

Mr. L.J. Murphy, fisheries inspector, stated on September 27th, 1939, that quahaugs were once very plentiful in Foxley river, and they disappeared about the same time as oysters there.

Mr. V. Travers, who has several oysters leases in the southern part of Malpeque bay, stated on September 18th, 1939, that quahaugs have been found in spots here and there during the past several years and are evidently "coming back". The abundance of quahaugs in this region at one time is evidenced by the abundance of empty quahaug shells found on the bottom while working on the oyster beds.

ACKNOWLEDGMENTS

The quahaug investigation, sponsored by the Fisheries Research Board of Canada, has been carried on at the Prince Edward Island Biological Station, under the direction of Dr. A. W. H. Needler, to whom I am much indebted for advice and assistance throughout the course of the work.

During the winter seasons, the work has been continued in the Department of Biology, University of Toronto. I wish to acknowledge the assistance given by many members of the staff and especially the helpful criticism and many valuable suggestions given by Dr. A. G. Huntsman, who has directed my studies here.

ILLUSTRATIONS

Figure 1. Distribution of Venus mercenaria in Canada.

2. Map of the Malpeque bay area, P. E. I.

3. Location of quahaug investigations in the Tatamagouche bay area, N. S.

4. Diagrams showing arrangement of Bideford river experiments.

5. Diagrams illustrating methods used in growth studies.

6. Maximum and minimum temperatures at low water level, Bideford river.

7. 1939 bottom temperatures and salinities in the Malpeque bay area.

8. 1940 maximum and minimum temperatures at five locations in the Bideford river growth experiments.

9. Bottom temperatures and salinities in Malagash basin.

10. Histograms showing the effect of exposure on growth and survival of quahaugs in Bideford river.

11. Histograms showing the effect of crowding and kind of bottom on growth of quahaugs in Bideford river.

12. Histograms showing growth of quahaugs in light and dark compartments of a floating tray.

13. Histograms showing the effect of eel grass on growth of quahaugs.

14. Histograms showing the effect of different amounts of water circulation on the growth of quahaugs.

15. Distribution of small quahaugs on the shore of Tatamagouche bay, N. S.

16. Annual catches of quahaugs listed in the Fisheries Statistics.

17. Age-height relationships of Port Hill and Paugh's creek quahaugs, from growth-ring measurements.

18. Height-length-thickness-volume relationship of Venus mercenaria.

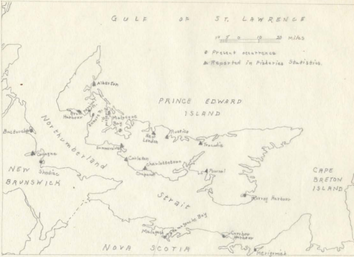


Figure 1. Distribution of *Venus mercenaria* in Canada

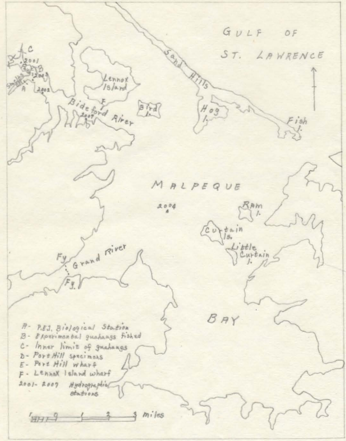


Figure 2. Map of the Malpeque bay area, P.E.I.

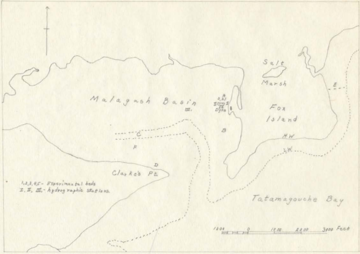


Figure 3 - Location of quahaug investigations in the Tatamagouche bay area, N.S.

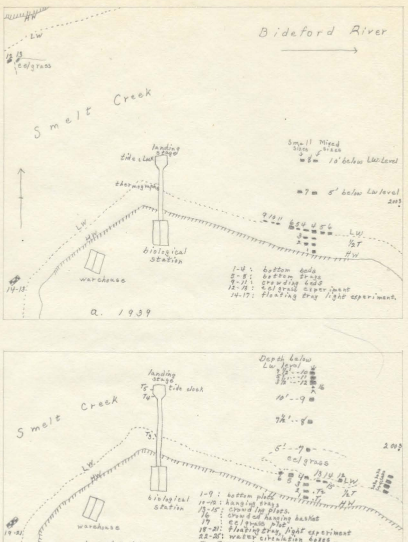
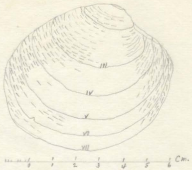
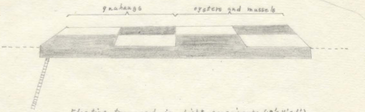


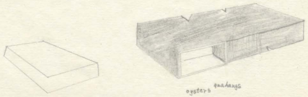
Figure 4- Diagrams showing arrangement of Bideford river experiments.



Right valve of 7 year old quahaug showing growth rings and notch
Filed at end of sixth year.



Floating tray used in Light experiments (12'x 4'x 6')



Bottom tray (4'x 2'x 6") Boxes used in water circulation experiments.

Figure 5- Diagrams illustrating methods used in growth studies.

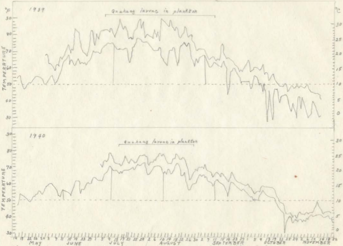


Figure 6- Maximum and minimum temperatures at low water level, Bideford river

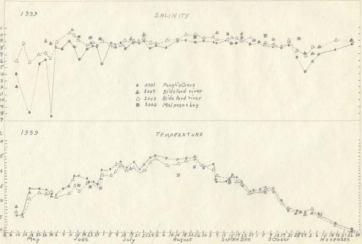


Figure 7- 1939 bottom temperatures and salinities in the Malpeque bay area.

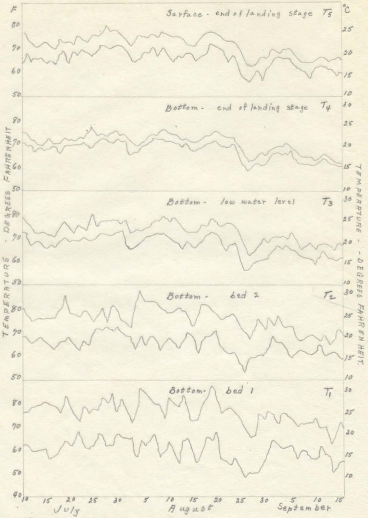


Figure 8 - 1940 maximum and minimum temperatures at five locations in the Bideford river growth experiments.

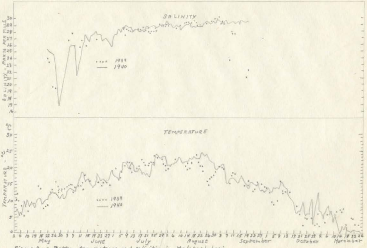


Figure 9 -- Bottom temperatures and salinities in Malpeque basin.

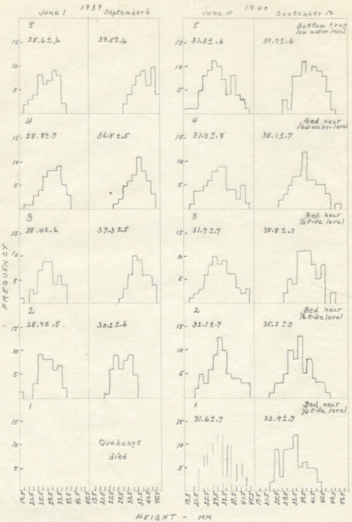


Figure 10.- Histograms showing the effect of exposure on growth and survival of quahaugs in Bideford river.

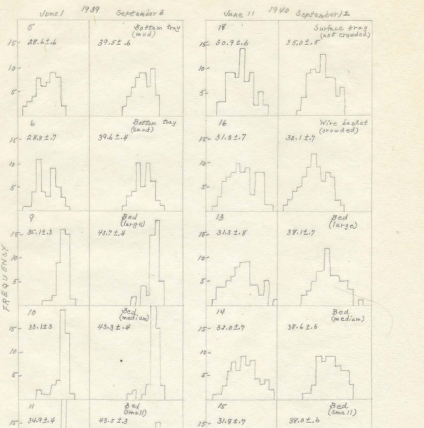


Figure 11 - Histograms showing the effect of crowding and kind of bottom on growth of quahaugs in Bideford river.

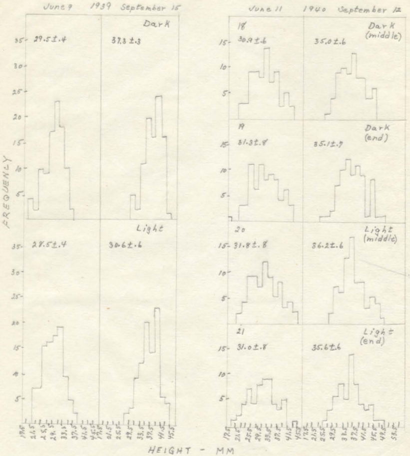


Figure 12.- Histograms showing growth of quahaugs in light and dark compartments of a floating tray.

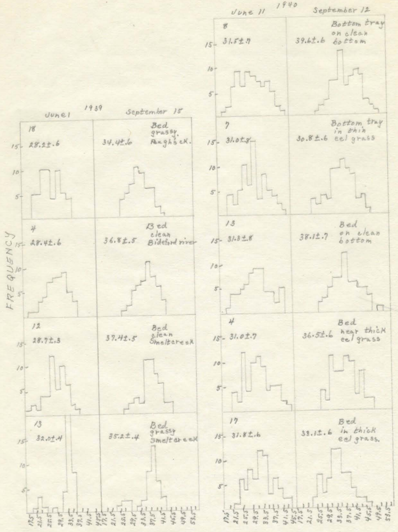


Figure 13. - Histograms showing the effect of eel grass on growth of quahaugs.

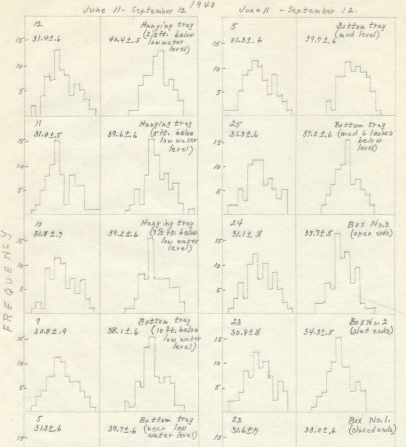


Figure 14. - Histograms showing the effect of different amounts of water circulation on the growth of quahaugs.

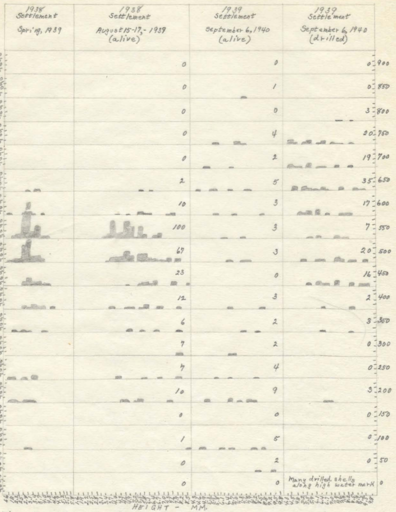


Figure 15- Distribution of small quahaugs on the shore of Tatamagouche bay, N.S.

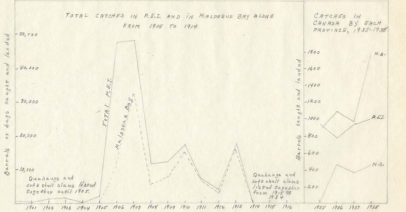


Figure 16 - Annual catches of quahaugs listed in the Fisheries Statistics.

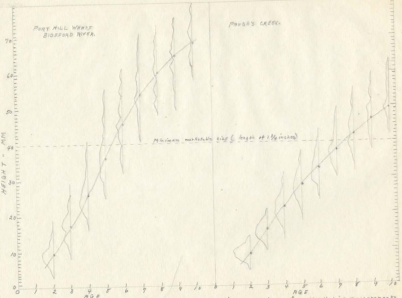


Figure 17.- Age-height relationships of Port Hill and Paugh's creek quahaugs, from growth-ring measurements.

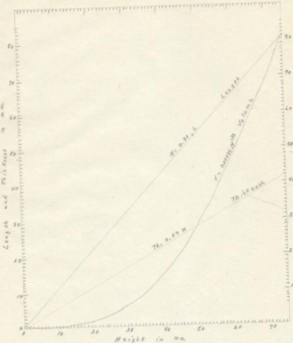


Figure 18. - Height-length-thickness-volume relationship of *Venus mercenaria*