IV. CONDITIONS GOVERNING EXISTENCE AND GROWTH OF THE SOFT CLAM (MYA ARENARIA).

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An examination of any extensive clam-flat will reveal the presence of clams only in certain localities: This would be true where digging had not been excessive, or even where there had been no digging. It perhaps would be impossible to-day to find large flats which are not dug, but if it were possible, clams would be found only here and there, large parts of the flats being barren. Certain areas, too, bear clams for a number of years, and then become barren, even when not dug excessively, and this might happen if they were never molested. We may sometimes witness, also, the gradual appearance and establishment of clams on patches of bottom which had previously been unproductive for long periods.

Without taking into account the all-powerful human factor, we may believe with certainty that the clam perpetuates itself only by overcoming many adverse circumstances, or more properly, by being able to take advantage of favorable conditions when they happen to arise. It of course is true of all organisms that they require, for existence, certain very definite and often complicated conditions in their surroundings, and that they will not be found where the peculiar combination of required circumstances and conditions is not present. We search for a certain species of violet not on open unshaded marshes, nor in high sandy woods, but in the rich earth of woods which contains a large amount of moisture in the spring when the plant is in blossom.

In looking out over a great expanse of sand which is exposed at low tide one is impressed with its monotony. There is here no contrast of light and shade. There are no elevations, and nothing to suggest ravines or valleys except the narrow gutters which carry off the last of the retreating tide. It requires a closer scrutiny to reveal any vegetation whatever, though it is present in places, and plays, as will be shown, an important part in determining the existence of the clam. Everything seems to be equally and monotonously exposed, and flat and barren. Yet the conditions are not by any means the same in all parts of the flat. The variations in character of bottom and tide are so great that clams may exist in one spot, the boundaries of which are sharply drawn, and may not live in others.

While we know in a general way some of the conditions that are necessary for the existence of certain animal forms, it is strange that they have not been more closely studied in specific cases among animals which are not domesticated. We have many reasons for the belief that these factors are often excessively complex, and hence difficult to discover. No doubt even a superficial study, however, would reveal in most cases many facts which would be worth knowing concerning the creature's relation to its environment.

There are two reasons for giving here a brief account of some observations upon the conditions controlling and determining the clam's existence. These few observations relating to the environment, though they leave much to be learned, may be of some biological interest, and, in the second place, they seem sufficient to formulate a plan for clam culture, which, in the now depleted condition of our clam shores, is certainly needed. They are not all included under one heading, but are scattered through the following account, and concern both the natural open flats and the isolated localities where the young sometimes collect, in enormous numbers, only to be destroyed. The conditions determining the possibility of mere existence, as well as those which allow the most rapid growth, have been studied more carefully in artificially constructed beds.

CONDITIONS OF NATURAL GROWTH ON BEACHES AND FLATS.

CHARACTER OF THE BOTTOM.

The soil must be somewhat tenacious.—It is impossible for clams to exist where there is much shifting of the bottom. The animal is buried deep, and reaches up to the surface only by its siphons. When foreign bodies, even sand grains in sufficient number, touch the sensory tentacles at the opening of the incurrent siphon, the whole organ is withdrawn for a greater or less distance into the burrow. It is probably true that a few sand grains coming in contact with the ends of the siphons will not cause their retraction, for we usually find more or less sand in the digestive tracts of clams which live on sandy flats. A larger quantity, however, will cause a withdrawal, and into the opening thus left sand may collect and, settling closely, so effectually close it that the siphons can not again be pushed up to the surface. Deprived of the food and oxygen-bearing stream of water, the clam quickly perishes.

Planting experiments will fail unless great care is exercised in selecting a bottom which does not shift. A certain bank on a large flat is recalled, which is said formerly to have yielded many clams. Its surface showed ripple marks, but clams were recently planted on it and at once were smothered. This experience also shows that conditions change, so that tracts once favorable for clams may no longer support them. The nature of some of these changes will be mentioned later.

Clams are sometimes found in beds of almost pure sand, but in such cases the water currents disturb the bottom very little. Even when established in such localities, however, their condition is precarious, for a gale or an unusually strong tide may at any time overwhelm them. Such a destruction has often been noticed. In this connection it may be stated that very slow currents sometimes prevent the existence of clams by depositing fine silt which they hold in suspension; this on settling has the same effect as shifting sand. Of course not all slow currents deposit, for many times they carry little or no sediment. At the heads of estuary-like arms of the sea which receive fresh water streams, one often finds such a deposit of mud, in which clams are not living, although clam food may be present in large quantities.

As in pure sand, so also in nearly pure mud, clams are sometimes present; but here also the action of currents and waves disturbs the bottom very little, and there is no very active deposition of silt.

Cementing substances.—(a) Fine sediments. The surfaces of clam beds are tenacious from several causes. When sand is mixed with fine sediments, its grains are held by this cementing substance. Clay, the finest of sediments, resists the erosive action of water to a considerable degree, and it is often found in more or less abundance on clam flats. Much of the best ground on a clam flat is often a tenacious mixture of sand and fine sediment.

(b) Growth of algæ. Another very important agency in rendering the surface tenacious, and thus preventing the shifting of its particles, is the growth of algæ, which forms a close, thin mat over certain areas, which are sometimes very extensive. The presence of the algæ gives a flaky or cake-like appearance to the bottom. It does not extend deep into the sand, but binds the surface grains closely enough to prevent their movement even by strong currents. This firm dark-green crust has been seen on beds in many localities, but the plants composing it have not been identified. Whether the growth occurs only where currents are swift has not been determined, but certain localities have been noticed to have this covering where the tide rushes with much force. This combination of firm bottom, which prevents erosion, and swift current, bearing abundant food, seems to afford the best conditions for clam growth.

(c) The growth of thatch and eelgrass. The growth of thatch plants or eelgrass may convert a waste of sand into a clam bed. Thatch is found on many beaches between the tide lines, and also covers large parts of clam flats. The plants grow close together. Their blades rise to a height of 2 or 3 feet, and their roots form a feltwork beneath the surface. As the conditions of the bottom change from year to year the growth gradually spreads from one place to another. In this mass of vegetation clams are often found in numbers, even when the soil is almost pure sand and the currents are swift. The reason that they are able to establish themselves is that the growth of so many plants prevents any shifting of the bottom, and still does not interfere greatly with the food supply.

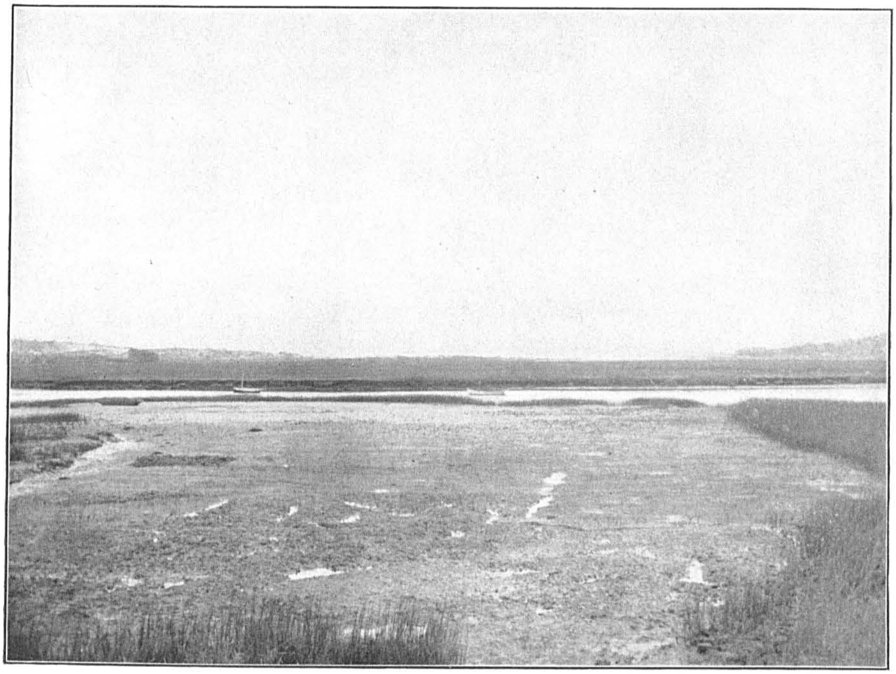
On account of the long wire-like roots it is very difficult to dig these tracts, and in view of the sadly depleted condition of our beaches and flats the circumstance is a fortunate one, for there is preserved in these beds a supply of breeding individuals which, if proper methods are employed, may reestablish areas rendered barren by excessive digging.

Figure 1 shows a clam bed artificially constructed in an immense field of thatch by removing the vegetation. Many of the roots of the plants still remain, however, and hold the soil firmly. Figure 2 represents a few feet of the surface of this bed, the numerous siphon holes indicating the great number of young supplied by parent clams living in the undisturbed thatch.

In the eelgrass, which grows between the tide lines as well as below, clams may also sometimes be found, but they are not numerous. Like the thatch, the eelgrass prevents the erosion of the bottom, but also probably makes it impossible for the clams to obtain a large amount of food, and, moreover, such areas contain a large amount of decaying vegetable matter.

FOOD AND WATER CURRENTS AS CONDITIONS OF CLAM GROWTH.

The food of clams is chiefly diatoms. Many species of these microscopic plants are attached to solid bodies, but those used by the clam for food swim and float in the water. Their number is enormously great, and their distribution apparently as wide as the seas, for they occur not only in all the shallow coast waters, but in the depths of the ocean as well. They form the food of many marine animals, but probably no forms are more completely dependent upon them than the group of mollusks to which the clam belongs. If one should follow a coast line, examining the water in every small bay and off every point, in every pool and eddy, and every swift stream, he would probably find diatoms constantly more numerous in some localities than in others. The reasons for this may be that salts in solution, which the diatoms use for food, are in greater quantity in one place than in another, and the differences in temperature affect the rate of reproduction, though this is usually a matter of some days. But whether or not clam food in a given volume of water is more abundant in one place than in another, some of it is present everywhere, so this condition of clam growth may be regarded as a constant one.



1. ARTIFICIAL CLAM BED.

2. SURFACE OF ARTIFICIAL CLAM BED.

It is true, however, that up to a certain limit, the number of clams which may exist on any area depends on the amount of food which they are able to obtain. Möbius has said concerning the food of the oyster, "The quantity of nourishment varies in proportion to the amount of water which passes over the beds." We will find that rapidity of current seems actually to have much to do with the number of clams which may exist on a given area. Besides this, evidence will be given to show that the increase in size of individuals depends upon the amount of food, that growth is much accelerated, and sexual maturity perhaps earlier attained where currents are swift. This of course is only possible where other conditions, such as the character of the bottom, are favorable.

In connection with the question of food and growth on natural beds, a word may be said concerning the existence of the soft clam below the low-water mark. The clam is almost always dug from beds that are exposed at low tide. Twice a day there is a period, of some considerable duration in some localities, in which the creature is unable to obtain food. It would seem that individuals below the low-water line, which are continually immersed, might thus have an advantage which should result in their more rapid growth. It is stated by Dean, in his study of the oyster in the South Carolina sounds, that "the best feeding conditions are during the rising of the tide, which appears to carry shoreward from the deeper water a number of pelagic forms. High tide contains the next highest percentage of oyster food. The poorest feeding conditions are shown at low water." But some feeding by submerged clams along the shore would be possible at low tide, and Mead gives experimental evidence to show that clams continually submerged actually do grow faster than those which are exposed at low tide.

In spite of the fact that food conditions are apparently favorable below the low-water mark, it seems doubtful whether submerged beds are relatively numerous. That there are many such beds along our coasts there is no question. They are present in the Essex River, in salt ponds east of Woods Hole, at West Falmouth, and one or two adjacent points on the shore of Buzzards Bay. Mead speaks of clams appearing in the market in February, 1900, which had been dug below low water in the Kickemuit River and at Wickford on Narragansett Bay. There are also beds at Salt Pond, Point Judith, and a large bed is known near Sag Harbor, Long Island. There are, no doubt, many more of these; but all these compared with beach beds may not be nearly so great in extent. This is a conjecture, and entertained only because, at many points, beaches have been examined and dug below the ordinary low-tide mark, at the full-moon tides, and apparently very few clams were present. It appears from a somewhat superficial examination, that clams on the ordinary clam beach extend down from the usual high-tide mark to the usual low-tide mark, very few being found below this region. More evidence is needed on this point. If this belief is well founded, there is some adverse condition which is more or less general and which is not now apparent.

ORGANIC MATTER IN THE SOIL.

There must be a comparatively small amount of decaying organic matter in the soil where clam growth is to be maintained. The reason is that carbon dioxid and humous acids formed by the decay of organisms have the effect of removing the lime from the shells of clams and lead to their death.

THE EFFECT OF OVERCROWDING.

It is usually easy to find between the tide marks on natural clam flats certain areas which bear clams so thickly set that growth is extremely slow. Such beds may maintain themselves from year to year, but evidence will be given to show that their condition is precarious. If, for any reason, some individuals die, others may be affected and the contamination eventually leads to the destruction of all. Much depends upon the nature of the water currents. Where they are rapid the danger is least. Some areas, therefore, may bear many more individuals than others.

THE SALINITY OF THE WATER.

In describing the conditions which are necessary for the existence of clams on natural beds it may be well to note the fact that, within certain very wide limits, clams appear to do equally well in water which is very salt or nearly fresh. Not only is this true, but they may be transplanted from one locality to another where the salinity is very different without being affected adversely.

ENEMIES.

The enemies of the adult clam are few. At one point on the shore above Cape Cod, the gastropod *Neverita* was observed digging beneath the surface and devouring mature clams. That other animals attack them in their burrows has not been observed so far as I know.

From what has been said it is perhaps clear that there is much variation in the conditions existing on a clam flat, and that the necessary combination of circumstances to allow clams to grow and reproduce is positive and definite. These conditions restrict the distribution to certain more or less clearly defined areas. They are constantly changing also, and clam beds appear now in one place and then in another. There probably are many other factors in the problem of the clam's environment which have not been observed. It may not be possible to discover them all even in an animal whose needs are so simple as the clam's, but a similar study of the conditions upon which an animal's life depends, if extended to other forms, would certainly give valuable knowledge in many cases.

CONDITIONS CONTROLLING THE DISTRIBUTION AND GROWTH OF THE YOUNG.

The egg of *Mya* unites with the male cell in the water. After fertilization a ciliated embryo is produced. This minute creature swims, and probably often is carried great distances by tide currents. Its early history has not been studied. Even after developing the bivalve shell it probably swims for many days before losing its cilia and settling to the bottom. The swimming larvæ may sometimes be taken in great numbers in a skimming net.

The habits of the young of *Mya*, from the time of settling to the bottom to the period when it finally digs into the soil to remain permanently, have been described.[a] The very small clam possesses a byssus thread. The byssus gland is probably developed at the time that the cilia are lost, for the creature needs this organ as soon as swimming ceases. The thread by which attachment is effected was seen in individuals that could not have been long upon the bottom. It is fixed to stones, aquatic plants, and other objects.

For some time the clam is too small to force its way into the bottom, though it early and persistently makes the attempt. A form with a shell which has attained a length of 5 or 6 mm. is able to burrow into almost any bottom. From the first the byssus may be cast off at will, and a new one produced. After attaining a lodgment a new byssus is formed and attached to sand grains and pebbles. In this way the animal is more or less perfectly anchored, and partially secured against dislodgment by waves or currents. It frequently leaves the burrow, wandering about by means of the greatly developed foot, and then repeats the process of burrowing. Finally it digs into the soil to remain permanently.

It is evident that the conditions determining the existence of the clam during this early period are different from those which affect the adult. The distribution of the young on the bottom and the subsequent struggle to effect a permanent lodgment are in some places peculiar. It may be well to consider these factors of the life problem apart from those which control the existence of the adult.

ENEMIES.

Floating organisms, very numerous in kind and infinite in number, constitute the food of a vast host of marine animals. Among these

[a] Observations on the life-history of the common clam. By James L. Kellogg. U.S. Fish Commission Bulletin, 1900.

pelagic forms are not only protozoa and protophyta, but also larvæ of higher animals. The swimming embryo of *Mya* has not been described as one of these, but most likely it also is subject to destruction in this way.

After becoming attached, and before it is possible to burrow, young clams are victims in great numbers to the rapacity of starfish. These pests begin their work of destruction while very young. They appear in the early summer, at the time when the young clams are falling to the bottom and struggling to obtain a lodgment. Some regions are much more subject to their ravages than others. Clams are not produced in equal numbers every year. In one year there may be great numbers, in the next very few. The same probably is true of starfish. Whether the conditions which allow of a heavy "set" of clams also result in the production of many young starfish is not known. It may be possible that this is not always so, and that in some seasons the young clams are comparatively free from the attack of their arch enemy. But some young starfish will always be present, and a few are capable of an immense amount of mischief. There is no doubt that, in the long run, the struggle of the young clams against this foe is a very severe one.

A few gastropod mollusks, such as the oyster drill, *Urosalpinx*, also prey upon young clams. Certain areas have been noticed where over 30 per cent of the small empty shells on the bottom have been drilled, but, although some small drilled shells are to be found wherever young clams are present, the losses from this source apparently are not often relatively great. Before the young clams are established in a burrow, other enemies, such as crabs and fishes, also prey upon them. The early life is a precarious one.

DISTRIBUTION OF THE YOUNG.

The swimming embryos settle to the bottom between and below the tide-lines. They are sown with a prodigal hand in shallow water and in deep, and only the very few fall upon "good ground" where they may have a chance to establish themselves. It is from these promiscuously scattered individuals that natural beds make good their losses. In certain restricted localities very great segregations of the young take place from accidental peculiarities of the surroundings. Their struggle for existence and their fate is interesting and instructive in many ways, and one such bed, which was observed with some care, will be described. It should be clearly stated that these thickly crowded beds are of very small extent as compared with natural beds of mature clams, and that they have no special significance, but are formed where conditions are peculiar, and usually disappear after a short existence. An attempt will be made to define the conditions which cause these peculiar segregations.

At West Falmouth, Mass., there is a small arm of the harbor which was found, in July, 1899, to contain vast numbers of small clams. No other locality along the shore seemed to possess many of them, although almost any clam beach at this time of the year showed a few individuals which had not long been settled there. They were found both above and below the low-water mark. Some very short strips just below low-water seemed to contain many small clams closely crowded; but though miles of the shore were followed, only two or three of these small patches were found. It is apparently only now and then that the conditions necessary for segregation are present. The beds at West Falmouth were extensive, and probably offered as perfect a field for the study of these segregations as could be found.

In order to explain some of the more important conditions, a figure of the small bay has been drawn. It is not perfectly accurate, but gives a fair idea of the ground. The bay is about 400 yards long. At its mouth it is about 40 and at its middle about 100 yards wide. The upper end of the bay widens considerably. It is probably nowhere more than 6 or 8 feet in depth at low-tide. One stream of water besides the inlet enters the bay. This is near its upper end, and is about 2 feet wide, the outlet of a pond of brackish water.

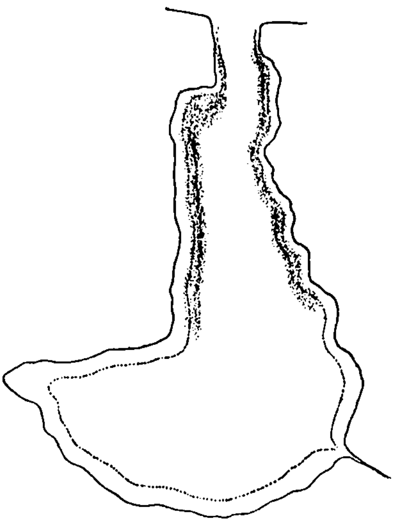


Diagram of beds of young clams at West Falmouth, Mass.

The heavy outline of the figure may represent the high-water mark, the dotted line mean low water. The stipples show the regions where the heavy "set" of young clams occurred. The lower half of the bay, between these lines of clams, was choked by a close growth of eelgrass. The wide upper end was covered with a soft oozy mass of fine sediment.

As shown by the stipples in the diagram, the small clams were distributed in two long strips below the ordinary low-tide mark, and parallel with the shores. These strips were nearly 200 yards long, and between two and three yards wide. The clams extended nearly to the eelgrass. They were nowhere present in the broad part of the bay, farthest from its mouth, nor were there any adult clams between the tide marks in this region. Adult clams were fairly abundant between tide lines opposite the young, near the opening to the bay.

On examining the tide currents it was found that there were two comparatively swift streams, whether the tide was rising or falling, which ran parallel to the shores, over the area occupied by the small clams. The current in the center of the bay was slow, on account of the great mass of eelgrass which filled it, so that a large part of the water entering and leaving took this course near the shores. These streams seemed to be like that part of a river which has reached its base level, for apparently they neither deposited nor eroded. In the broad upper part of the bay the water was quiet and a large quantity of fine silt was deposited, making it impossible for clams of any age to exist.

It is probably generally true, as in this case, that small clams are found crowded in great numbers only where currents are comparatively rapid. This has seemed to be the condition in other localities where they have been found. At the lower ends of these strips they were crowded most closely, and the currents were most rapid here, though still not so swift as to disturb the bottom. Toward the upper ends of the strips clams became gradually less numerous, where, also, the velocity of the currents was diminished.

It is important to notice that the small clams were not entirely confined to the beds below the low-water mark. With a fine sieve it was possible to find them between tide lines. They were not numerous, however. It has been stated that the densely packed beds below low-water mark appear in few localities. Yet from almost any clam bed between tide lines in the early summer a few of the young may be obtained. The number is insignificant as compared with that where young clams are segregated in a bed by themselves. It is probably these scattered young that make good the annual losses of a clam bed, and not the numbers of the crowded lower bed, even where it is present and in close proximity.

Such a separation of young below low tide and adults between tide lines as shown at West Falmouth seems strange, and the further history of this lower bed is equally remarkable.

We may attempt to explain the position of the young in the following way: For several weeks during the breeding season in 1889 (May, June, and July), when this large "set" occurred, the embryos undoubtedly swam in vast numbers in the water. It is probably safe to say that during such a season millions of embryos grow from the eggs of a single large female. These embryos swim, and it is possible that the course taken by them may be influenced by differences in the intensity of light, changes in the temperature of water or air, or by differences in the specific gravity of the water. But their movements must be very largely determined by tide currents, and it is not easy to imagine that these other conditions are the causes of this peculiar distribution, or that they have any important influence upon it.

We will probably find our explanation in the action of a definite current of water which contains swimming embryos. Imagine a wide stream entering the mouth of this bay. It carries embryos which it has received from beds outside. At high water embryos are added, also, from beds of mature clams inside. The incoming stream is checked by the eelgrass in the center of the bay. Much of the water is deflected to the sides, and a much larger quantity of it passes over the bottom there than elsewhere. That is to say, very many more embryos are borne over this line parallel to the beach than anywhere else. When the tide runs out it takes the same course as on entering, and for the same reason.

We may suppose that for several weeks embryos are continually dropping to the bottom, losing their cilia, and attaching themselves by the byssus. That this strip receives accessions of small clams for several weeks will be demonstrated. Evidently, then, many more would reach the bottom here than elsewhere. At the same time a few would fall upon the eelgrass or on the bottom on which it grows, and some would also find lodgment between the tide lines at the end of a flood and the beginning of an ebb tide. This may account for the distribution in this bay, and in similar cases observed there is also a swift, narrow current.

In the summer of 1899 this set of small clams maintained itself for some little time, the reason being that sediment was not deposited over this area. No doubt great numbers of embryos carried into the wide upper part of the bay also settled to the bottom there. But they were unable to establish themselves and undoubtedly perished, because the slacking current deposited silt, and quickly smothered them. None were found along the shores of this part of the bay. This soft deposit was probably often agitated by unusual tides, or even by rains or strong winds. It is possible for the clams to live only where a current is running with a velocity great enough to prevent a deposit.

These facts seem to be sufficient to account for the distribution and maintenance of young clams, but it may seem strange that similarly crowded areas were not found more often when a search was made for them near many other clam beds. But even when the currents were favorable, the embryos in the water, although deposited in the same manner, may have been so few in number as to escape observation.

The conditions governing clam distribution are in some respects similar to those determining the set of oyster spat. The swimming young of the oyster fixes firmly to foreign objects. Its distribution is often perplexing. Sometimes, as in parts of Long Island Sound, the attachment takes place in deep water. On the "coon" oyster banks of the South Carolina sounds, attachment rarely occurs below low-tide mark. In some regions the set is at one time high, at another time low.

Several suggestions have been made in an attempt to explain these peculiarities of distribution. They include the influence of varying density of the water, the softness of the bottom, the suspension of silt in deep water, and changes in the composition of the water of oyster beds. Dean[a], who carefully studied the problem, concluded that the slime-covered bottom probably prevented fixation, and that silt suspended in the water made it impossible for the oyster to live, these being the chief factors of the distribution.

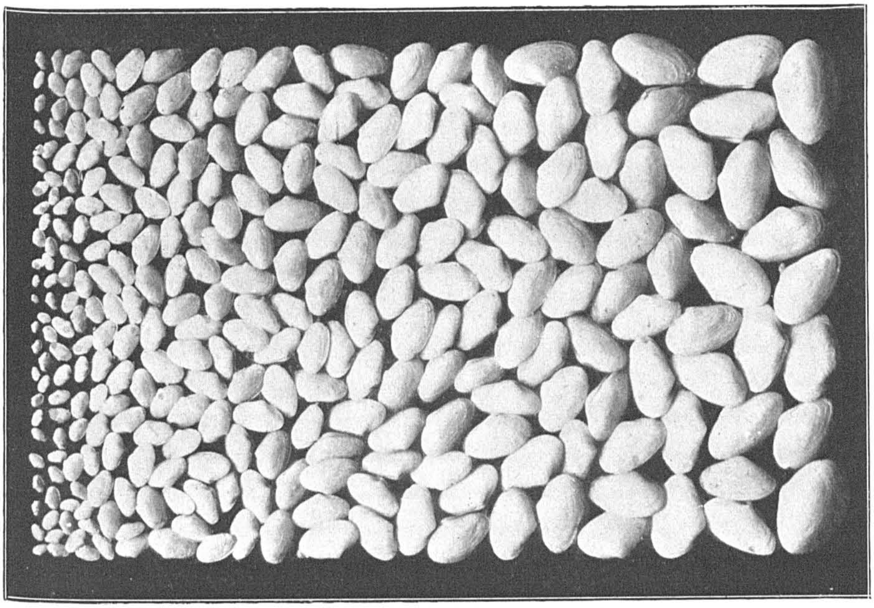
The habits of the young oyster and of the young clam are very different in many respects, but the segregation in both cases to definite and limited localities is probably from the same cause. Over any area a greater number settle to the bottom where currents are swift. At the same time, many sink on other parts of the bottom. Wherever silt is absent either may become established; in a silt deposit neither can live. The favorable localities may be near the shore or in deep water, as the case may be. In some places the presence of enemies must also be considered.

We may conclude that on a clam beach or flat, embryos settle to the bottom both above and below the low-water mark. Fewer embryos lodge above the low tide line than just below it, because of the recession of the water. Where definite currents are present we find the greater number of the young. Where currents keep the bottom clean but do not erode, clams are for a time able to establish themselves. In distributions like this one at West Falmouth it may be asked what is the relation between the two separated beds of clams. The answer may be given with some certainty that there is none. It seems probable that the mature clams between tide lines are recruited only slightly, if at all, from the beds lower down, and that their number is added to by the small clams which, in the beginning, settled between the tide lines and were able to establish themselves. The multitude constituting the lower bed seems ultimately to perish.

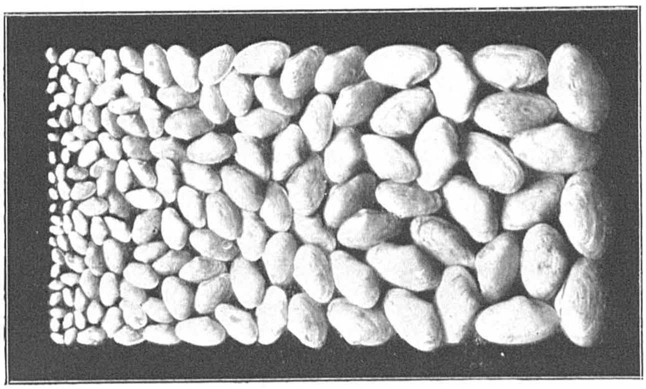
The bed of young clams was first found at West Falmouth on July 10, 1899, and during the remainder of the summer was examined often. On this date clams were very thickly set. Numbers of them were small, many being about 1 mm. long, while the maximum length was about 11 mm. The clams shown in figure 3 were selected from a large number to represent the minimum and maximum sizes of those on the bed, and also, as nearly as possible, the relative number of intermediate sizes. No doubt many smaller than those represented were lost through the meshes of the sieve.

The ages of these clams can only be conjectured. The larger are probably from 5 to 7 weeks old; the smaller may have lived 1 or 2 weeks. The breeding season in Buzzards Bay extends from the latter part of May to the early part of August, reaching its height in late June and early July. Here and there very small clams are found as

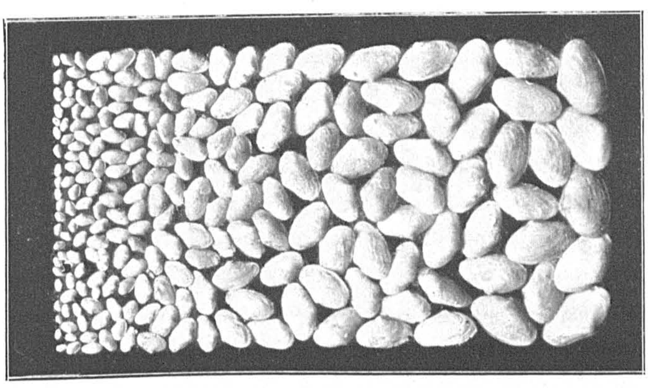
[a] The Physical and Biological Characteristics of the Natural Oyster Grounds of South Carolina. By Bashford Dean. Bulletin of the U. S. Fish Commission for 1890.



5. July 27, 1899.



4. July 17, 1899.



3. July 10, 1899.

SIZES OF CLAMS FROM BED AT WEST FALMOUTH, MASS.

late as September, but after the first of August the number diminishes rapidly.

Figure 4 represents clams taken in the same way on July 17. There still appear individuals as small as on the previous date, but they are less numerous. The larger ones had attained a length of about 13 mm.

On July 27 another lot was taken and is represented in figure 5. At this time very small clams still seemed to be making their appearance, and there is an increase in the maximum size.

On August 4 (fig. 6), clams but recently settled to the bottom were not numerous. The maximum length was about 18 mm.

Figure 7 shows individuals taken on August 16. There were still found at this time a very few that had recently settled to the bottom. The maximum size was about 20 mm.

When the beds in this bay were first found on July 10, there were already so many empty shells lying on the bottom that they formed a white line which could easily be traced for some distance by one standing on the high bank. Many of these, however, were of previous generations. As time went on, more and more empty shells appeared, until in August the surface of the bottom over the beds was covered with them.

It appeared, then, that even well within the breeding season, when embryos were still settling to the bottom in great numbers, the destruction of the beds had begun. On July 10 numerous dead shells were found in the bottom as well as on its surface. Many of these, too, were clearly not shells left from some previous season, for they were found with the organic matter of the body not yet decayed. The death of individuals spread rapidly, until, on August 16, a square foot sometimes yielded no more than half a dozen live clams. By September 1 practically all were dead. In the meantime on the beach above the mature clams were holding their own fairly well, but it is a significant fact that digging during the second week of August showed that many of them also had recently died.

It is not easy to explain this complete destruction. During this same summer Mead was studying the same phenomenon at Wickford, R. I. He says: "In one case a certain point of the shore was set in the middle of July as thickly as the clams could burrow, but by the month of August hardly a young clam could be found. They apparently washed out or were covered with shifting sand. In another locality, about 40 rods from the last, the set was also very thick. These clams continued to be abundant throughout the summer and autumn, and, though meanwhile they were somewhat thinned out, were yet very numerous on December 4. I think one important factor in their wholesale destruction lies in the fact that they set much thicker than they can grow, and a great many are crowded out."

It has been stated that a careful examination of the West Falmouth beds gave no evidence of an erosion of the bottom. Even the light empty shells on its surface were not moved to any extent by the currents, so that clams in these beds nowhere seemed to be washed out or covered with sand. There were places, it is true, where they were so closely crowded as nearly to touch each other, but over the greater part of the beds there was ample space for all. Yet everywhere the same destruction occurred. Mead's explanation did not apply here.

Almost everywhere among the empty shells on the surface living clams were found. Even when 20 mm. in length, a clam is ordinarily able to cover itself in the course of a few minutes, and smaller ones are more active than the larger. Small clams have been described in a previous paper as being restless and as having the habit of coming out of their burrows, wandering for short distances, and again digging into the sand. Yet these individuals among the empty shells usually seem to be inert.

The following explanation is offered for the destruction on these beds. The small clams are constantly coming to the surface of the bottom. When exposed they are subject to the attack of starfish, crabs, and fishes, and though these enemies were very scarce here, some clams may have been destroyed by them. Because so many of those lying among the empty shells could not be revived on being removed to what appeared to be more favorable localities, but remained motionless until they died, we may suppose them to have been greatly exhausted from lack of food. The wandering habit of the small clam will account for the appearance of so many dead shells on the surface where there is no crowding or washing out. It was stated that a very large number died in the burrows also. If lack of food is the explanation for the beginning of the destruction, however, there must have been a time, after the death of a certain proportion of the whole number, when food in the water was sufficient for the remainder. As these grew and each demanded more nourishment, others would die, until a new equilibrium was established. Instead, almost complete annihilation occurred.

Another factor may have entered into the problem. The contamination of the water, by the bodies of so many dead, finally may have caused the death of all. This is suggested because on several artificial beds in which the clams were closely crowded the destruction of all seemed to occur from this cause.

The assumption that lack of food and the spread of infection from dead clams were the causes of the extermination seems to be confirmed by the fact that death apparently occurred first where clams were most crowded, and spread from those points. By September 1 almost every clam was dead at the lower ends of the beds, nearest the mouth of the bay, where they had been most closely set, while at the upper ends, where they were scattered, several still survived.

It is not clear why, in this case, the mature clams on the beach above the low tide line escaped, though the water flowing over them possibly may have contained sufficient food for so small a number, and the contaminated water would remain largely in the rapid stream over the lower bed, both on the ebb and flood tide. A number were found dead, and the beaches were dug very little by clammers, who might have injured many so as subsequently to have caused their death. Very likely other factors not observed entered into the extermination of the small clams.

VARIATION OF THE SET OF DIFFERENT YEARS.

Much attention has been given to the production of oyster seed. In Europe and in the United States it has been found that the productiveness varied greatly in different seasons. There is nothing regular about it. Favorable and unfavorable seasons may alternate for a time, or there may be a succession of productive or unproductive years. Möbius[a] says: "In 1860 there were many young broods upon the beds near the island of Ré and near Rocher d'Aire and but few broods at Arcachon; 1861 was a good brood year for all three places; 1862, bad for the island of Ré and good for both of the others, and in 1865 there were very many young in the bay of Arcachon and but few near Rocher d'Aire and the island of Ré. The causes of these variations are thus local in their action, but what they are is not fully known, beyond the fact that a definite density of the water is most favorable for egg laying in the European oyster.

There has been no accurate study of the spawning of the clam. The variation in the size of the set is, however, much like that of the oyster. While the young in 1899 appeared in great numbers along the shores of Buzzards and Narragansett bays, in 1900 they were very scarce in both localities. At Duxbury and Essex the set was said to be favorable in 1900. These places are north of Cape Cod, where the biological conditions are very different from those on the south side. The conditions seem to be local.

The variation of the set may be due to the fact that few or many ova are produced at different times, or it is possible that eggs are always abundant, and that at times some unknown condition prevents the swimming embryos from establishing themselves on the bottom. It is not yet possible to say what effect the degree of salinity of the water has upon the production of the sexual elements of the clam, or upon the development of the embryo. It is probably little, because, unlike the oyster, the welfare of the adult clam is not determined by a limited and definite density.

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[a] Die Auster und die Austerwirthschaft. Karl Möbius. U. S. Fish Commission Report for 1880.

RATE OF GROWTH OF THE YOUNG.

When figure 3 is compared with figure 7 it is seen that the increase in five weeks is considerable. The maximum length on July 10 was 11 mm., on August 16, 20 mm. It must be remembered that during this period the number on the beds was enormously great. In one region, where clams seemed to be most crowded, a count showed an average of 1,100 to the square foot on July 10. With so great a number the food supply must have been inadequate. Growth probably would have been much more rapid if food had been more plentiful.

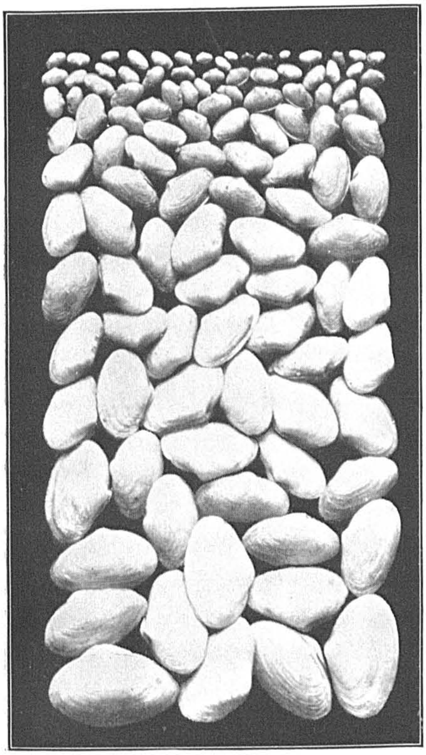
Several thousand clams were removed from these beds on July 27 and planted below low-water mark at Woods Hole at a point where conditions seemed to be favorable. They were placed in a swift current where no other clams were present. For some reason the great majority soon perished. Mead showed that clams planted in a box of sand suspended in the water from a houseboat grew faster than those which were crowded on the beach.

CONDITIONS DETERMINING EXISTENCE, AND THE RAPIDITY OF GROWTH ON ARTIFICIAL BEDS.

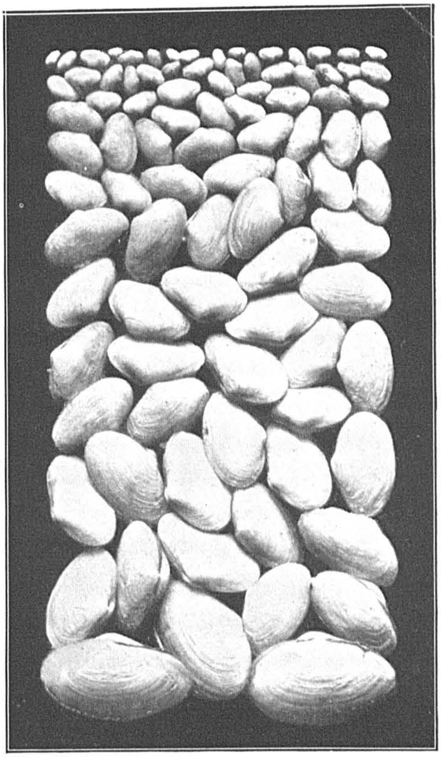
It has been shown that there are certain definite conditions which are necessary for growth on natural beaches and flats, and that when these conditions are not present clams can not live. It has also been stated that the distribution of the young on the bottom depends upon peculiar conditions of the environment. We may now consider a series of experiments designed to test these observations. They will show also that the artificial rearing of clams may be accomplished with little labor and at small expense. Oyster culture in the United States, though much more simple in its methods than in Europe, is many times as difficult and expensive as clam culture would be, and in the present depleted condition of our shores clams are sometimes worth nearly as much per bushel as oysters.

From the foregoing description of the small clams, it is evident that a study of such cases will not demonstrate the possibilities of clam growth. The conditions of growth are most unfavorable on beds so greatly crowded. Early in the summer of 1899 a number of artificial beds were prepared, and during the summer many thousands of clams were planted upon them. Beds were placed in various localities where the surroundings were different, and each was left undisturbed for a year.

The main objects of the experiment were to determine the rate of growth under as many different conditions as possible—in slow as compared with rapid currents; in closely crowded and thinly planted beds; the relative amount of growth of small and large clams; growth after exposure for different periods; growth after a transfer from brackish to salt water, etc.

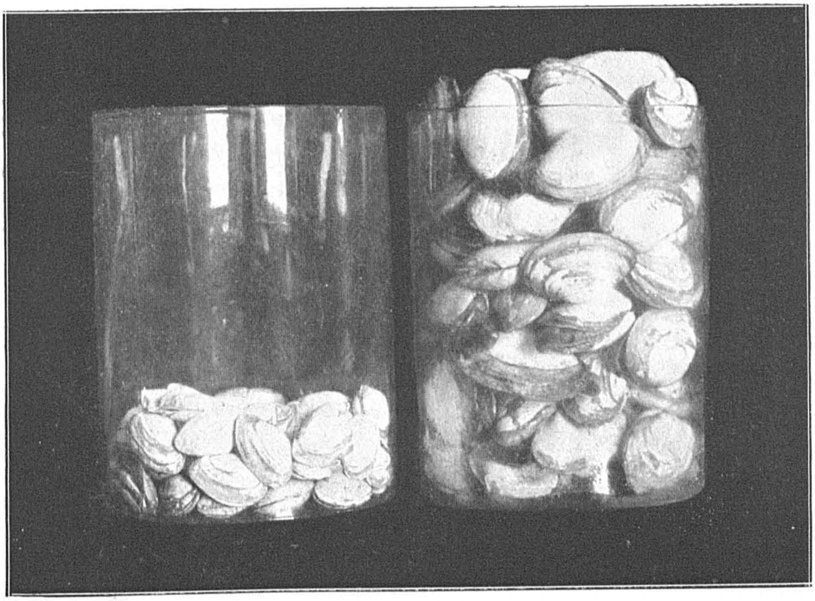


6. August 4, 1899.



7. August 16, 1899.

SIZES OF CLAMS FROM BED AT WEST FALMOUTH, MASS.



8. INCREASE IN VOLUME AFTER ONE YEAR OF CLAMS FROM EXPERIMENTAL BED WITH PRACTICALLY NO CURRENT.

Any facts bearing on the length and variation of the time required for reaching the period of sexual maturity in animals should be of scientific interest. The conditions determining the length of this period are known in few animals, and speculations like those, for example, on the meaning of the duration of their life can not safely be indulged in without many more facts of this nature. It certainly seems to be true in this case, as in that of the accelerated growth and maturity of oysters in French claires, and of the young starfish studied by Mead[a], that the amount of food determines whether the period shall be long or short. The question of the growth of clams has a severely practical side also. In any attempt to rear them for commercial purposes, rapidity of growth is the most important thing to be considered. On it depends, to a large extent, the practicability of culture methods.

Many years ago, when the oyster supply began to decline in Chesapeake Bay, and an increasing demand caused prices to rise, the life history and habits of the form were studied and various methods of artificial culture devised. These have been practiced for some time with great success on the north Atlantic coast. It is found that, under favorable conditions, a marketable size is reached after a growth of three or four years. In Europe this period is sometimes shortened to a considerable extent by improving the food supply. Great profits are realized, even when that length of time is consumed in awaiting the harvest.

The period of growth in the soft clam is much shorter than this. A growth of two years, under fair conditions, should produce a clam of marketable size, and culture methods are very much simpler and cheaper.

THE DECREASE IN THE SUPPLY.

For nearly a quarter of a century the clam supply of the north Atlantic coast has been steadily declining. During the last five years it has fallen off very rapidly, and in many places the industry is nearly destroyed.

In the report of the U. S. Fish Commission for 1894, statistics are given showing the production of clams in New England from 1880 to 1892. These tables are valuable, because they indicate a great decrease in the market sales, and in a case like this it is impossible to obtain statistical evidence of the condition of the beds in any other way. Yet statistics are not always conclusive. In this case, for example, the tables for the State of Maine show an increase in the production from 1880 to 1887, in the former year 318,383 bushels being marketed, and in the latter year 608,780 bushels. From that time until 1892 they indicate a steady decrease to 416,806 bushels. But there was not so great

[a] Twenty-ninth Annual Report of the Commissioners of Inland Fisheries of Rhode Island. 1899.

a decrease in the actual supply on the beds, for since that time sales have increased, until in 1898 Maine marketed 1,109,936 bushels.

This is mentioned to show that, while a table of market sales usually may indicate the condition of the beds, there may be some cases in which it will not. An examination of the beds themselves, however, can give only an approximate and incomplete estimate of their condition. Where this has been done the indications are that, with the exception of the state of Maine, these tables gave a correct estimate of the conditions of clam beds in the New England States at the time of their compilation, and that the decrease has been more rapid since that time. Long Island, too, is fast repeating the experience of New England. Even in Maine, the beds now seem to be suffering from excessive digging, and the State, in 1899, passed a law prohibiting the sale of clams in any form from June 1 to September 15 of each year. From a practical standpoint, then, there is great need that the conditions of growth be determined by experiment.

EXPERIMENTS.

METHODS EMPLOYED.

The beds for the experiment were laid out at Woods Hole. The locality was not the most favorable that might have been selected, for the beaches are narrow and almost everywhere stony, making digging difficult, and the rise and fall of the tide is not great. These conditions made planting and the removal of clams very difficult also, and clams for planting were not easily to be obtained in the vicinity. The locality was chosen because certain short strips of beach are controlled by the U. S. Fish Commission, and upon them trespassing could be prevented. Because conditions of growth were unfavorable, however, it is certain that the results obtained here could be realized almost anywhere where clams will grow at all.

Clams to be planted were collected from many parts of Buzzards Bay and Vineyard Sound. Some were dug at West Falmouth, others at Mattapoisett and Hadley Harbor, while a great many were taken from the brackish waters of Long Pond, east of Falmouth Heights.

The plan was to prepare beds by digging clams already in the ground, and to plant small clams which should be left for a year before being removed. The length of these clams was determined by a measurement of every individual. They were measured in eighths of an inch. Those of a size were collected and planted together.

It was necessary that there should be some means of determining positively, when finally removed, the exact position of clams whose size had been determined at the time of planting. A method by which this was most successfully accomplished was devised by Dr. H. C. Bumpus. On a selected area, four posts were driven inclosing a space

10 feet square. A light, portable frame of the same dimensions was constructed and divided into square feet by means of small ropes. At the time of planting, this frame was placed upon a bed, just fitting between the stakes, and clams were placed in any of the small squares, a record of size and number being made in the corresponding square of a diagram in a notebook. When clams were removed the frame was again placed in its original position.

It should be said that clams of the size of those planted do not remove themselves from their burrows, but remain where they are placed. It has been stated that small individuals wander, but the habit seems to be abandoned before they are an inch long.

As already explained, clams were measured in length before planting and again after a year of growth, to determine the increase. A statement of the increase in length gives no adequate idea of the actual increase in size, however. This increase in volume was determined by displacement in water. A clam 1 inch in length diplaces approximately 2.25 cc. of water. One 2 inches long displaces about 11 cc., or nearly five times as much. An individual measuring 3 inches displaces about 43 cc., or is about nineteen times as large. In measuring displacements, results vary in different cases. Some individuals are thick and wide, others narrow in proportion to the length of the shell. When being measured some are more contracted than others. Thus a comparatively large number was measured in order to determine the average displacement in each set, and the results obtained are accurate enough for the purpose.

In order to be certain of the position of individuals in the beds, a sharp-pointed stake was driven into the ground to a depth of several inches, and on its withdrawal a clam was thrust siphon end uppermost into the hole. Working in this manner, it was possible to place them with some rapidity. Upon a hard, gravelly beach, four men at one time planted 3,000 in two hours. In a soft beach twice that number might have been planted in the same time. There seems to be no reason to doubt that clams finally removed from any square were the ones originally placed there. The beds were probably not molested by clam diggers. There was some apprehension lest, during the winter, ice should destroy the stakes marking the corners of the beds. Fortunately not a stake was removed or broken.

Clams all of the same length when planted will of course vary somewhat in size after a year's growth. When these were dug, they were again measured and arranged in a series of different sizes, the number in each set being counted. The arithmetical mean of the series was then determined. The volume of the mean of the series was compared with the volume of the clams when planted, and the percentage of increase in volume calculated. For example, in a certain bed planted on July 13, 1899, the clams were 1⅜ inches long. They were removed on July 4, 1900. The mean of this series, expressed in eighths of an inch, was 20.952, or nearly 2⅝ inches. The volume of a clam 1⅜ inches long is 4.5 cc. That of an individual 2⅝ inches in length is 32 cc. Hence the increase in volume is about 688 per cent.

RESULTS OF THE EXPERIMENTS.

It should be remembered that on many of the beds, especially upon several which were placed near the upper end of the small harbor at Woods Hole, conditions of growth were not favorable. About the middle of July the pebbles and stones on the surface were coated with a dense growth of the seaweed *Enteromorpha.* Diatoms, which form the food of clams, are to be found in great numbers among the threads of this alga, but the mat was so dense that it must have interfered seriously with the process of obtaining food from the currents. Great masses of dead eel grass, which was barely floated at high tide, also remained upon the beds for days at a time during the summer, and must have interfered greatly with the food-bearing currents.

Increase with practically no current.—Many thousand clams were placed in the beds at the head of the harbor. These, for the reasons mentioned, yielded the smallest proportionate increase, and may be considered first. The following table illustrates the amount of growth of several sizes on the poorer beds:

Size when planted.	Approximate percentage of increase in 1 year.	Size when planted.	Approximate percentage of increase in 1 year.
	Per cent.		*Per cent.*
1 3/8 inches	556	2 1/8 inches	139
1 4/8 inches	422	2 2/8 inches	109
1 5/8 inches	347	2 3/8 inches	78
1 6/8 inches	284	2 4/8 inches	38
1 7/8 inches	210	2 5/8 inches	28
2 inches	190		

Figure 8 presents to the eye the increase of volume in the set 1⅝ inches long. The jar to the left holds 75 individuals of that length, while the other contains an equal number the size of the mean after growth—2⅜ inches. The increase in volume is 347 per cent.

In making these estimates of growth there is in each case a slight inaccuracy, but it is apparent that in comparing relatively small series, or even large series, to show the increase, absolute precision in all the details of the calculation would be no more to the purpose than are these figures. For if a similar experiment were carried on with equally exact detail in a region where conditions of food, time of exposure, etc., were slightly different, the results would vary from those obtained in the first case, *and we can not determine the varying possibilities of different conditions or surroundings* with any knowledge which we now possess. Here we simply describe the conditions so far as we know them and show the approximate increase, and the number of clams planted (8,500 in the 17 beds) is great enough to make our result reliable.

The errors are slight. They arise in two or three ways, and tend to balance each other. (1) The unit of the scale of measurement was an eighth of an inch. If a clam being measured for planting was slightly less than $1\frac{1}{8}$ inches in length, it was placed in the 1-inch group. This method was also followed in measuring clams after growth. (2) When the mean of a series after growth was determined, a decimal above 0.5 was expressed by the next highest, and when below 0.5 by the next lowest unit in the scale. Thus if the mean size in a given series were 20.6 eighths, it would be called $2\frac{5}{8}$, if 20.4, $2\frac{4}{8}$ inches.

The decrease of the percentage of growth shown in the table, from the smaller to the larger individuals, is not perfectly regular. This may have been because the number in some series was much greater than in others, and also because the conditions on one bed were not exactly like those on another. Some beds were each day longer exposed than others, and there may have been other differences in the surroundings.

Amount of variation in a single series.—The variation in length of the individuals of a single series was considerable. For example, in a series of 140 clams, which were $2\frac{4}{8}$ inches long when planted, the series when dug included clams from $2\frac{6}{8}$ to $3\frac{3}{8}$ inches in length. A few seemed to have grown very little. It is possible that some may have been overlooked in preparing the beds for planting, and that these clams were not those planted, but small forms already present and not removed. From the pebbly nature of the surface it was not easy to detect all the siphon holes. On account of the difficulty in removing all small clams in preparing the beds, these afterwards appearing in the series, probably the calculated percentage of growth is less than it would have been if the beach when planted had been perfectly clear of clams. On the other hand it was comparatively easy to note the presence of large clams, and probably few of them were left.

In one bed in another locality the ground was most carefully dug and examined for small clams. Practically all must have been removed. The clams planted here were all exactly 1 inch long, but at the end of a year the length varied from $2\frac{1}{8}$ to $2\frac{7}{8}$ inches.

Growth in a slow current.—Over the beds first described there was practically no current, but only a rise and fall of the tide. The following table, prepared as was the first, shows the approximate increase on several beds placed on a beach near the entrance to the harbor, where the current was more marked than at its head. The current here, however, was not at all strong, and was discerned only by the bending of the eel-grass below the beds. On the best clam bottoms in other regions it is many times as great, yet the difference between these two localities was great enough to make a decided difference in the rate of growth.

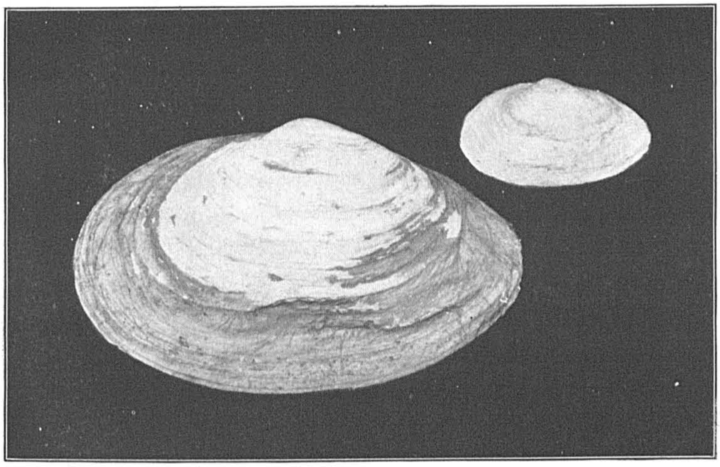
About 5,000 clams were planted here, but unfortunately for our comparison with the other beds, most of them were of smaller size than in that region. A very large number, however, were 1⅝ inches long when planted, and many of this size were placed in the beds already described. In the first case the approximate increase in clams of this size was 556 per cent, in this region 711 per cent.

Size when planted.	Approximate percentage of increase in 1 year.	Size when planted.	Approximate percentage of increase in 1 year.
	Per cent.		*Per cent.*
1 inches	1,150	1⅜ inches	768
1¼ inches	802	1⅝ inches	711

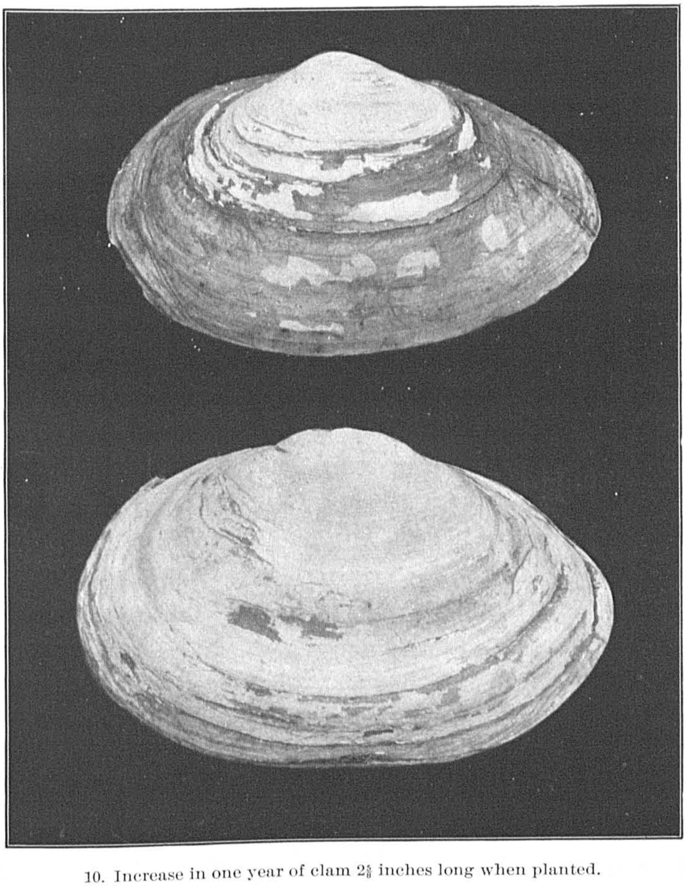
We find, as would be expected, that the percentage of growth is greater in the smallest clams planted. In the first table, clams 1⅝ inches long when planted, increased 556 per cent in the year, while those 2⅝ inches in length increased 28 per cent in the same time. This is illustrated in figures 9 and 10. In each figure the upper clam is of the size planted, the lower the size of the mean after a year's growth. The clams in figure 9 were planted in a more favorable locality than in the other case, but the result would have been much the same if both had grown on the same bed. Under the most favorable circumstances a growth of several years must be necessary to produce a 6-inch clam—and individuals of that length are sometimes found.

A point of practical significance in this connection is that clams from 1 to 1.5 inches in length, which are much too small for sale, may, in the course of a year, when not too greatly crowded, reach a fair marketable size. Now on most clam beaches and flats areas are to be found on which these small clams are so closely crowded that growth is hardly possible. Sometimes these areas are suddenly depopulated, and sometimes they exist for years with little increase in the average size. If these clams were dug and properly spaced, the increase would certainly be very great. There would usually, of course, be no object in planting clams much more than 2 inches long.

The spacing of clams.—Another fact must be noticed in connection with the increase shown in these tables. All these clams were planted close together for this region. Five were placed on every square foot. The beds, also, and there were 17 of them, were all placed as closely as possible. Without doubt if the clams had been more widely spaced growth would have been still more rapid. A good clam ground would probably support several times as many as this.



9. Increase in size in one year of clam 1 inch long when planted.



10. Increase in one year of clam $2\frac{3}{8}$ inches long when planted.

CLAMS FROM EXPERIMENTAL BED WITH MORE MARKED CURRENT.

It is evident that no general rule can be given for the spacing of clams. Where food-bearing currents are rapid clams may be closely placed, and where they are slow the spacing must be greater. Only experiment will determine the optimum space for a given area.

The proper number of clams to be planted on any area can not be expressed in bulk measurement. In an early note on the Essex experiment in clam culture[a], it was stated that clammers estimated that 500 bushels of small clams would be necessary for planting 1 acre. Suppose that clams to be planted varied from 1 to 2 inches in length, and that all were to be left until of marketable size. If planted in the same locality they would require an equal spacing. But assuming that 1 bushel contains 4,000 clams 1 inch long, it would require nearly 7 bushels to hold 4,000 clams 2 inches long, and the single bushel of the first should be spread over as great an area as the 7 bushels of the larger size. Even if beds were of the same character in all places the proper number to be planted could not be expressed in bulk measurement.

There remains to be described the growth on a special bed with which extraordinary pains were taken. This bed was selected at a point slightly below those the increase of which has been described in the second table. The current was here more rapid, and the clams were each day immersed for a somewhat longer time. The bed was all very carefully dug, that it should bear no clams not measured and planted. In it were placed several hundred clams exactly 1 inch long. They were in good condition when planted on August 17, 1899. To protect the bed a wire netting was firmly fastened over it, being attached to iron posts and held down in various places by long wire staples. The bed certainly was not touched for a year.

On August 16, 1900, the clams were removed. Their length varied from $2\frac{1}{8}$ to $2\frac{7}{8}$ inches. The arithmetical mean of the series was 18.969 eighths, or almost $2\frac{3}{8}$ inches. Comparing the volumes of clams of 1 inch and $2\frac{3}{8}$ inches it was found that the latter was 14.37 times as large as the former, or that there had been an increase of 1,337 per cent in volume. This amount of increase is represented in figure 9, and was the greatest obtained on any of the beds.

On the beach above, where the current was not so rapid and the time of exposure greater, clams of the same length increased in volume but 1,050 per cent. It appears, then, that rapidity of growth depends directly upon the amount of food, the food supply depending upon the velocity of the current.

This growth took place upon a beach and not upon a flat where currents have full sweep. A feeble current ran parallel to the beach, but the bed itself was partially surrounded by eelgrass. The food supply here must have been poorer than upon many clam flats, and it should

[a] Report of the U. S. Fish Commission for 1894.

not be difficult to obtain even a more rapid growth in the most favorable localities.

Comparative growth on high and low beach.—Several thousand clams were planted in rows extending from the high-tide mark to a position some distance below ordinary low water, in order to determine, if possible, the relative effects of long-continued submergence and frequent exposure. Unfortunately the attempt failed, because, in ignorance of the number which a given area would support on these beaches, the clams were placed so close together that they all died. That fact itself is one of the most important demonstrated by these experiments, and will be mentioned later.

Among the 17 beds at the head of the harbor were several which were exposed only at full-moon tide. It is a curious fact, for which there is no apparent explanation, that in almost all of these the greater number of clams died. They were not more thickly planted than on higher beds, though their average size was slightly larger. On the other hand, as already stated, a very rapid growth was obtained in another locality on a bed placed near the ordinary low-water mark, the lower part of it usually being submerged.

Death from overcrowding.—This may be due, as in the case of the small clams, to two things—the lack of sufficient food and the contamination of the water by the decaying bodies of dead clams. When a clam dies others near it seem to be affected. When several die the infection seems to spread rapidly, so that the death of a few may lead to the sudden destruction of many or all in the vicinity. To illustrate this, two beds were planted thickly (9 to a square foot) with clams 1⅜ inches long. Among these were a few individuals which were nearly dead from exposure. Their bodies probably quickly disintegrated. The majority in each bed were apparently in the best condition.

One of these beds was in comparatively quiet water; the other where currents were constantly running back and forth over it. A year after planting, the first bed contained no living clams. The shells of the dead were easily found, though in some cases nearly disintegrated. When measured they were found to be, without exception, the size of those planted. This indicates that the few injured clams died at once after planting and that the contamination spread rapidly, all being destroyed before any had grown.

The other bed, in the more rapid current, contained a few living clams. A great number of empty shells was found, but these were not all of one size, as in the first case. They exhibited a gradation from the size of the living forms, which were the largest, to shells of the planted clams. The condition of this bed probably is to be explained by the supposition that the early death of a few injured forms did not immediately affect all the others, this being prevented by the rapidity with which the currents carried away decaying matter. Growth may have continued until, from the effects of crowding, others died, and this process finally left only the few.

Two other beds may be cited as illustrations of this point. They were placed on the same beach where the most rapid growth was obtained. Each contained 150 square feet and extended from near high water below ordinary low water. In the first, 1,900 clams were planted, varying from 1 to 1¼ inches. In the second were placed 1,200 clams of the same sizes. All seemed to be in perfect condition.

In a year's time almost all were dead on both beds. An examination revealed shells of all sizes up to about 2.5 inches. The few living clams were nearly 3 inches long. The great majority of the empty shells were very little larger than those planted, so that death must have overtaken them soon after being put in the ground. Death from lack of food or from injury may have occurred in a few individuals. The decaying bodies of these may in turn have caused the death of others, and this must have come about quickly.

Which is more important in accounting for this destruction, lack of food or contamination of the water, it is difficult to say. Scarcity of food alone may account for it up to a certain point, as explained in connection with the death of small clams on natural beds; but finally there should have been a certain percentage remaining for which food in the water was sufficient. Nearly all died, however, and it is not easy to see why they should, unless it may have been from this infection of the water by the bodies of dead clams. At all events there are several cases to show that too great crowding is likely to lead to the loss of all clams planted together. Where currents are rapid more clams may live than where they are slow, and the capacity of any beach or flat must be determined by experiment.

THE CHARACTER OF THE BOTTOM INFLUENCING GROWTH.

Natural beds are found on muddy, sandy, or rocky beaches. Whether soft or hard, the bottom merely offers protection from enemies. Buried under several inches, the clam reaches to the surface with its siphons. Through them one current of water bearing microscopic food is led down to the body within the shell and another passes out bearing waste matter.

It may be assumed that the abundance of food in the water is the only important feature of the surroundings, but, in some ways, the character of the soil may also be important. Two beds were marked in a soft bottom which contained much decaying vegetable matter. Other conditions seemed to be much as in the neighboring beds. The surface of this peaty mass did not shift. Water currents, food, and exposure by tides were certainly not very different on other productive beds 50 yards away on the same beach. But of 1,500 clams planted in perfect condition, apparently, only 3 remained alive. It was found, too, that they had not all died at once from the contamination of the water by dead clams, for many shells were found larger than the size planted. Most of the shells fell to pieces at a touch, being disintegrated by the humus acids and carbon dioxid formed in the decay of vegetable matter. In this case the shells may have been destroyed by the acids faster than they could be built up by the animal, thus leading to the death of the clam. In several other beds where decaying matter was present in the soil, a partial disintegration of the shells of living clams was very noticeable.

On clam shores, patches or even extensive tracts containing a large amount of organic matter may usually be found. At one time these areas may have produced clams. Many times the changes which bring about the adverse conditions have been observed. The great November gale of 1898 converted a large clam bank on the Duxbury (Mass.) flats into a barren waste by throwing upon it great masses of eelgrass and then covering it with a thin layer of sand. Sometimes beds upon which eelgrass grows are covered with sand and the plants die and contaminate the soil. When such changes occur, clams that may be present are smothered, and subsequently it is impossible for others to establish themselves permanently. It may be that these beds eventually become purified and bear clams, but we have no evidence that this is so. If there is a recovery, it is probably very slow, for instances are known of beds which have remained barren for many years after being overwhelmed in this manner by storms.

The amount of lime in the soil has much to do with the character of the shell. "Paper shell" clams are found in beaches of pure sand. Where lime rock is exposed shells become thick and heavy. Lime in the soil also neutralizes humous acids formed by decaying matter.

Without mentioning other cases which have been noticed, it seems probable that the character of the soil itself should be considered carefully in any attempt at clam culture.

THE EFFECT OF EXPOSURE.

In one experiment nearly 20,000 clams were dug, measured, and planted. Before they were put into the beds, it often was necessary to allow them to lie exposed in the heat of July from one to two days. This treatment killed many, and others were so affected that, upon being handled, they contracted their siphons and closed their shells with much indifference. None were planted, however, which were not able to contract completely. In cooler weather, they undoubtedly would have remained in good condition for a much longer time, but it was plainly shown that an exposure of 48 hours to the summer heat was enough to injure them to such an extent that death quickly followed after planting. Exposure under these conditions for 36 hours led to the death of many, but those which had been out of water for a day, even when exposed directly to the sun for some time, as a rule seemed to be injured very little.

For example, of a large number dug on one low-tide, several were planted 24 hours later, and many survived. The remainder of the same lot was planted under similar conditions after 48 hours of exposure, and almost all died. Their shells showed that they perished before any growth had taken place. None were crowded in planting, and the tide currents were more rapid than on the majority of the beds. In this case the destruction probably should be ascribed not to the contamination of soil and water by the decaying bodies of a few, but rather to the fact that all had been too long exposed before planting.

Several similar cases were noticed, and it seems safe to conclude that during the hot summer months clams for planting can not be exposed safely longer than a day. In culture work this would not often be necessary.

TRANSFER OF CLAMS FROM FRESH TO SALT WATER.

Clams frequently are found in localities where the water is nearly fresh. In such regions diatoms are usually abundant, and clams flourish. Near Falmouth Heights a large, nearly fresh pond supports many clams, and several thousand of these were transplanted directly to the very salt water at Woods Hole. When not too long exposed in the transfer, they seemed to be entirely unaffected by the change, and grew exactly as well as others planted near them which had been taken from the salt water of Buzzards Bay. Though an attempt was made to transfer clams from salt water to this fresh-water pond, the time was too short to prepare a bed properly by removing clams already present in it, and the results are not to be depended upon. The transfer from salt to fresh water probably could be made as well, however, and this possibility of ready transfer is a point of importance, for small clams often may be abundant in waters of one density near favorable planting grounds of another.

In many, if not in the majority, of marine animals a more or less definite amount of salt in the water is necessary for their existence. Even in the case of oysters, which are near relatives of the clam, a slight variation in density determines whether they may live or not. While it is true that the life of individuals may not suddenly be ended when they are placed in water more or less salt than the normal amount, it is also true that reproduction is interfered with, or even entirely prevented by the slightest changes. The American oyster differs from the European species in its requirements and perhaps is not affected by such slight changes. In the case of the latter, Dean[a] says, "The degree of density of the water is one of the most important factors influencing spawning," and states that a few thousandths of a degree (e. g., 0.002) makes a decided difference. It is of great interest, and of great importance, from an economic point of view, that one of the chief difficulties with which the oyster has to contend in perpetuating itself does not affect the soft clam. A good "set" seems to occur as readily in brackish as in salt water. There seems to be no definite optimum density controlling either the production or the establishment of the young.

SUMMARY.

Conditions of natural growth on beaches and flats:

The soil must be tenacious. On a shifting surface sand grains may pack into the burrow on the withdrawal of the siphons, preventing subsequent extension to the water, and leading to the death of the clam. The more rapid the current the more tenacious must be the surface to prevent erosion.

Surfaces of clam beds are tenacious from several causes.

(*a*) Sand is mixed with cementing substances like fine silt or clay. (*b*) There is frequently a growth of an alga on the surface which prevents any erosion, even in swift currents. (*c*) Clam beaches are sometimes stony or gravelly, and hence are not shifted. (*d*) On extensive flats thatch vegetation prevents a shifting of the surface, and clams frequently are found in great numbers among the plants. (*e*) Eel grass, between tide lines, in the same way, unless growing where the soil contains much organic matter, sometimes prevents erosion and allows clams to establish themselves.

The food of clams consists of diatoms. They are everywhere present, and this condition may be regarded as constant. The amount of food varies in proportion to the rapidity of currents. In large measure the rapidity of the current determines the number of clams that may exist on a given area.

Organic matter in the soil sometimes prevents the existence of clams.

Overcrowding leads either to the rapid extinction of all, or prevents increase in the average size.

Within certain wide limits, the salinity of the water has no apparent effect in determining the existence of clams.

The enemies of adults are few. The gastropod mollusk *Neverita*, however, has been observed below the surface devouring clams.

The conclusion is that on natural beaches and flats the conditions necessary for existence are complex and definite, restricting the dis-

[a] European Methods of Oyster Culture. U. S. F. C. Bulletin for 1891.

tribution to clearly defined areas. These conditions are constantly changing and shifting the regions where clams may become established.

Conditions controlling the distribution and growth of the young:

The egg develops into a swimming larva which finally settles to the bottom and attaches by means of a byssus. It is some time before the clam is able to burrow. In the meantime it is exposed to many dangers. The young appear scattered on beaches and flats, but at times are segregated in numbers so great that they have scarcely room for lodgment. Such a locality was found at West Falmouth, Mass. These segregations occur below the low-tide mark, and are accounted for by the rapidity of narrow currents where the water bears many swimming embryos. There seems to be no relation between such beds of young and the beds of mature clams on the beaches above them, the latter being recruited only from the few small clams that chance to settle between tide lines and there establish themselves.

On the West Falmouth bed the maximum size on July 10, 1899, was about 11 mm., the minimum about 1 mm., though smaller clams might have been found with a finer sieve than the one used. The larger clams were probably from five to seven weeks old. Several observations on the growth were made from time to time until September. On August 16 the maximum length was about 20 mm. Very small individuals still appeared, though few in number, showing that the breeding season was not yet entirely ended.

Even at the height of the breeding season, early in July, some clams were dying. By August 16 very few remained alive. The explanation of their destruction seems to be (1) lack of sufficient food and (2) the contamination of the water by the decaying bodies of dead clams.

The set varies in different years, sometimes being great, sometimes small.

Conditions determining existence and rapidity of growth in artificial beds:

Experiments were made to determine the rate of growth under many different conditions. The methods are described in detail. Woods Hole harbor was not a favorable locality for showing the possible rapidity of growth. At the head of the harbor, where there was practically no current, series of clams (each of which was measured) from 1⅜ to 2⅝ inches in length were planted. At the end of a year these extremes of the series had increased in volume 556 and 28 per cent, respectively. In another locality where there was some current, clams from 1 inch to 1⅜ inches had increased 1,150 and 711 per cent in volume. In one bed placed where the currents were most rapid, clams exactly 1 inch long were planted, and in a year had increased 1,337 per cent in volume. The conclusion was reached that the rate of growth depends directly upon the amount of food.

Several experiments showed that death from overcrowding was due to lack of food and the spread of contamination from decaying bodies.

Experiments indicated that the character of the bottom had much to do in determining the existence of clams, those soils containing much decaying vegetable matter destroying the shells faster than they could be built up, the active agents being the humous acids formed in the decay of plants.

Exposure out of water in the heat of summer caused death after twenty-four hours.

It was found to be possible to transfer clams from nearly fresh water to very salt water without apparent injury.