XVIII.—AN EXPOSITION OF THE PRINCIPLES OF A RATIONAL SYSTEM OF OYSTER CULTURE, TOGETHER WITH AN ACCOUNT OF A NEW AND PRACTICAL METHOD OF OBTAINING OYSTER SPAT ON A SCALE OF COMMERCIAL IMPORTANCE.

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Introductory.

The developments made within the last six years show that the solution of the most important problems in oyster culture, by means of artificial methods, starting with the egg, is possible. The question of questions in oyster culture is, "*In what way is it possible to certainly secure an abundance of spat under conditions which can be controlled, and within such an area and at such a cost as will render it possible for persons possessing the proper knowledge to undertake spat culture or the actual propagation of the oyster as a business?*"

This may seem an extravagantly sanguine view to take of the matter. Nevertheless it is true that it is actually possible to begin at once, with the knowledge now in our possession, and not only be successful, but also be so to a degree which must completely revolutionize the business of the bed culture of this mollusk in open waters.

I.—Historical.

My own connection with the oyster question dates from 1880, and during the years intervening between the latter and 1885 the writer has devised and had constructed no less than twenty forms of incubating apparatus in which it was hoped to obtain spat from artificially fertilized eggs, such apparatus ranging in size from less than a cubic foot to large ponds four feet deep and several hundred square yards in area. The basic idea in all of these except three was the use of filters with a continuous or an interrupted tidal flow of water through the apparatus; the function of the filters was to confine the fry in the inclosures.* In none of this apparatus, except in one form of it, I am obliged to admit, was it found that results of startling economic importance were obtained,

* The trouble with filters, of any form whatsoever, is that they soon clog and become useless. They can therefore never be successfully used in any practical system of propagation.

and while this is true, it is also a fact that observations and results were obtained which indicate that there is a feasible method of almost unlimited productiveness; all that is needed being the proper combination of conditions which it is now proposed to describe on the basis of well-known facts which may be verified by any one who will take the trouble to do so.

Besides devising the various forms of incubating apparatus, during the interval of time mentioned, the writer, in conjunction with others, used in his experiments no less than eighteen forms of collectors or cultch in coves, ponds, and in the incubating apparatus, for the purpose of affording the free-swimming fry surfaces to which it could affix itself. Some of these forms of collectors were previously used in France, Holland, England, Portugal, and Italy, to obtain the spat of *Ostrea edulis*, and long before any one had thought of introducing them into our own country; indeed, the use of cultch or collectors of various kinds has been in vogue for a long period, in fact, if historical records are to be trusted, since the days of the Cæsars. The practice of strewing oyster shells upon the sea bottom as cultch, to which some of the many billions of fry diffused through the water could become affixed, seems to have been inaugurated by the French Government about 1851, under the direction of Professor Coste, the distinguished embryologist of the Collége de France. This practice seems since then to have fallen into disrepute or partial neglect abroad, but has been practiced with such magnificent results in this country that the method is now applied in Long Island Sound, in the deeper water, on a scale which is without an approach or parallel in any other part of the world. The principal inaugurator of this system seems to have been Mr. H. C. Rowe, of New Haven, Conn., who, about twelve years ago, began sowing shells in deep water. Ridiculed at first, Mr. Rowe has finally made such a splendid success of his system that he sows as many as 100,000 bushels of shells annually upon what is now probably the most colossal oyster-farm in the world, embracing as it does about 15,000 acres of the bottom of the sound, off the city and vicinity of New Haven.

While this system is eminently successful, it is also attended with considerable risk, great quantities of shells being sometimes wasted in consequence of the fact that in some seasons no set of spat whatever becomes attached over large areas, owing to adverse conditions of weather, currents, or the inroads of sediment, which coats the surfaces of the shells and asphyxiates the minute embryos which have recently become adherent to this kind of cultch. The same objection holds in reference to all the other kinds of collectors hitherto used. Strewing shells on the bottom renders only their upper surfaces available, so that the amount of spatting surface is meager to begin with. The under convex surface of the shells is partly in contact with the bottom, and is largely useless, while the upper or smooth side soon becomes coated with sediment, unless the currents are quite strong over the bottom. Other collectors, such as brush, tiles, slates, in their various modes of utilization, are too expensive and give a too inconsiderable surface of attachment to justify the outlay incurred in their construction as practiced in Europe. The methods which make tiles available abroad are not the methods which will justify their use in America. In Europe labor is cheap, and oysters are so valuable that they are a luxury to be enjoyed only by the wealthier classes. Not so in the United States, where the middle classes along our eastern seaboard can consume the luscious *Ostrea virginica* as part of their every-day fare without feeling that they are living extravagantly.

Other investigators besides the writer have sought to develop some method of artificial culture for the American oyster. Foremost amongst these must be mentioned Prof. W. K. Brooks, of Johns Hopkins University, who, in 1878 and 1879, for the first time investigated the development of our American species, using artificially fertilized eggs for the purpose. Later, Lieut. Francis Winslow, U. S. N., associated himself with Professor Brooks at Fort Wool, and actually operated two different devices with that object in view. Another pupil of Brooks, the late Henry J. Rice, also devised some apparatus for the purpose, and is, I believe, the investigator who has maintained artificially fertilized embryos of the oyster alive for a longer time than any one else. None of these efforts have, however, so far as I can learn at this writing, yielded results which were of direct practical application, or have been of sufficient promise, when applied on a large scale, to justify their continuance in their original forms.

About the same time, or during the period intervening between 1880 and 1884, investigators were busying themselves with a study of the large diœcious Portuguese oyster, *Ostrea angulata* of Europe. The first published account of the artificial fertilization of this species was by an American, Lieutenant Winslow, who in 1880, while with an American man-of-war lying off Cadiz, Spain, obtained successful results with the method of artificial fertilization first used by Brooks. Subsequently M. Bouchon-Brandely, of the *Collége de France*, took up the subject and carried on further investigations, and in his efforts to attain practical results reported very remarkable success in obtaining spat on a moderately large scale. He, however, adopted a system which had been previously used on a small scale by the writer. Subsequently, and unaware of what American investigators were doing, this experimenter used the closed-circuit system devised by McDonald, but which the French experimenter operated in a different manner.

Out of this grew the system of operating inclosed ponds with the help of the tides during the years 1882 to 1885. But in consequence of a radical misapprehension of the essentials of a rational method, I am forced to admit that no results of great practical value were the immediate outcome of any of these experiments. While the work has been immediately fruitless, mediately it has *not* been so, for the light gained as the result of all the work of others, as well as my own, now enables me to state with certainty *why* we have failed.

Failure is a harsh word, and it is a humiliating one as well; but it will soon be seen that we have been cultivating a lot of fallacies and erroneous conclusions which led to it. In a word, we have neglected to think about what we have observed, so as to elaborate a practical theory of spat culture.

II.—FALLACIES AND ELEMENTARY PRINCIPLES.

1. **Where fixation occurs.**—The fact that artificially fertilized oyster fry would rise at a certain stage of development to the top of a tumbler or beaker filled with sea-water, when allowed to remain undisturbed for a time, has been supposed to have some bearing upon the question as to how collectors should be disposed in the water; that is, whether at the surface or the bottom. It is now known that such a habit on the part of the young fry when in perfectly still water does not indicate that the collectors should be placed at the surface. On the contrary, numerous facts can be cited to show that the fry will affix itself and become spat at any level in the water. This was indicated by the results of the closed circuit experiment conducted by Colonel McDonald and myself in 1882, when in a small apparatus, covering not over a square yard, we succeeded in getting fry 24 hours old to affix itself to the sides of the glass vessels and old oyster-shells contained therein. In the course of this experiment not less than 100,000 young oysters were adherent at one time to the available surfaces inside this apparatus. No greater success in obtaining adherent oyster fry from artificially fertilized eggs has ever been recorded either in Europe or America.

Another set of facts, observed in 1883 at Cohasset, Mass., indicates that fry will adhere in the open water in the same way. Pole buoys were there found thickly covered with very young spat as far as they were immersed. On some parts of these poles as many as 100 young oysters might have been counted upon a single square inch of surface. At other places in the same vicinity oyster and clam shells lying on the bottom were thickly covered with spat, so that as many as 150 were actually counted on a single valve.

The conclusion, therefore, is that fixation occurs at all levels, and that cultch 1 foot below the surface stands as good a chance of having a set of spat adhere to it as others at a depth of 30 feet. In other words, *spat can be obtained in the whole range of all three of the dimensions of any given body of water.* This is the first principle in a rational theory of oyster culture.

2. **The surfaces of collectors.**—Another fallacious belief is that the fry will adhere most readily to a rough surface. This conclusion was shown to be erroneous in the experiments with the closed circuit apparatus at Saint Jerome's Creek in 1882, as well as by all the facts observed at Cohasset and Stockton in 1883. Anything, no matter how smooth it is, will serve

as a spat-collector; in fact, the greatest number of spat ever observed by the writer per square inch has been found on the smoothest possible surfaces. The fundamentally important prerequisite in oyster culture, however, is that *all spatting surfaces shall remain clean for a long enough time to allow the spat to become well established* This, I would say, is the second great and important principle, which is never to be lost sight of in practical oyster culture.

3. **Artificial fertilization.**—A third erroneous conclusion is, that artificial fertilization is impracticable, and can yield no valuable results. Large bodies of water may be artificially charged in all three dimensions with embryos as effectually as a small body of water used in the closed-circuit experiments. It has also been found that pumping sea-water which *is* charged with embryos through a steam-pump will not injure the oyster fry. Spat was obtained from water into which oysters had spawned and which had passed through the steam-pump employed to fill the supply tanks with the sea-water used in incubating fish ova at Cherrystone in 1881. Several young oysters were found in the tanks at the end of our season's operations, and doubtless many more would have been found had a large supply of cultch been put into the tanks when our work began.

It is, therefore, obvious that, no matter in what way the water is charged with embryos or fry, provided plenty of cultch is used, spat will be obtained. This has been illustrated by the abundant set of spat obtained from artificially fertilized eggs on the cultch used in the closed-circuit experiments of 1882, and in the results of the pond system, in which filters were used, from 1882 to 1885; and by the spat obtained by us from native embryos at Cherrystone in 1881, and by Mr. Mather in 1885. Of the nature of the experiments of Brooks and Winslow in 1882 I am uncertain, but they also, I believe, obtained attached embryos on shells laid in troughs, through which water charged with embryos was allowed to flow. The embryos employed by them were, I believe, obtained by artificial fertilization.

The remarkable set of spat observed at Cohasset, Mass., in 1883 may be contrasted with the number of artificially fertilized embryos found fixed to the sides of the jars and to the cultch contained in the closed-circuit apparatus used in 1882, for I believe it may be affirmed without overstating the case, that a greater proportion of artificially fertilized embryos were found to be adherent in the last instance than naturally fertilized ones in the first. The third principle determining success in oyster culture will, therefore, *consist in having the water used in spat-collecting well charged either with native or with artificially fertilized embryos, or with both.*

4. **Condition of collecting surfaces.**—It is well known that *the cultch, in order to be available or to afford an eligible surface for the existence of the adhering fry, must be clean.* This, I repeat, may be considered to be a cardinal principle in practical oyster culture. If the cultch becomes

thickly coated with vegetable life, such as filamentous algæ, or diatoms, or with incrusting animal life, such as bryozoa barnacles and ascidians, ooze or sediment, the chances for the survival of the adherent fry and its capability of growing into spat is greatly diminished or rendered quite impossible. Diatoms will very often increase on such surfaces with prodigious rapidity, and form a thick coating which will greatly interfere with the life of the very first adherent stages of the oyster. In fact, the latter are asphyxiated in prodigious numbers from such causes.

5. **Why oyster fry adheres to the lower side of collectors.**—Another fallacious belief which has gained some currency is that the fry will adhere to the under surface of collectors or cultch more freely and in greater numbers than to the upper surface. This is apparently but not actually true. The reason that more spat is found on the under side of the collectors is simply because the sediment deposited on the cultch from the water by the action of gravity will fall only on the upper and not on the under surface of the collectors. In this way it happens that the fry which adheres to the upper surface of the cultch is soon smothered, while that on the lower survives. It will be readily understood that it is a very easy thing to smother an organism which is sedentary like the diminutive young oyster, since it at first measures only $\frac{1}{500}$th of an inch in diameter.

6. **Light.**—This brings us to the question of light and the part it plays in the life of the infant oyster. Light seems to be of subordinate importance, for it has been found that the fry which adheres to the under and shaded side of the cultch, if the conditions are otherwise favorable, will grow just as rapidly as that found on the upper side in the direct light. Indirect light, therefore, seems sufficient for the purposes of the health of the animal.

7. **Density of water.**—The density of the water is also to be considered in relation to the hygiene of the oyster. It has been found that it can exist in water barely more than perceptibly saline, or in water having a density nearly equal to that of the ocean. While it may be said that its favorite abode is in bays, inlets, and the mouths of rivers adjoining the sea, and in which the density, as measured by the hydrometer, would range from 1.003 up to 1.0235, the writer has himself found oysters living in this great range of densities, or in water little more than brackish on up to that which is not far from as saline as that found in the open ocean.

It appears also to be a fact, though I give it as such with some hesitancy, that the greatest amount of spat falls in water having a density ranging from 1.014 to about 1.022.

8. **Bathymetric distribution.**—The bathymetric distribution of the animal ranges from the shore line to a depth of probably ten or twelve fathoms. Deep-water culture is now becoming a prominent and profitable feature of the oyster industry in Long Island Sound, since its feasi-

bility has been so thoroughly tested by Mr. Rowe. Where the tide rises and recedes from natural banks, thousands of the animals are often exposed for several hours during low tide without apparent injury. The animals, under such circumstances, when the tide recedes apparently retain sufficient sea-water between their valves to meet the demands of respiration during the time they are uncovered.

9. **Horizontal distribution.**—Their range of distribution along the eastern coast of the United States is from Damariscotta Bay in Maine south to Florida and the Gulf of Mexico. The most important beds industrially are those of Long Island Sound, Chincoteague, Delaware, and Chesapeake Bays, and their tributaries. The States of Maryland and Virginia possess the greatest area of natural beds, though the importance of the still more southern beds is probably not yet fully appreciated.

10. **Influence of temperature.**—The temperature of the water in which the oyster ordinarily exists throughout the year ranges from something under 32° to 90° Fahrenheit. On the exposed banks in shallow water many are frozen during the winter, and it appears that if they thaw out slowly, freezing does not usually injure them.

In summer, or during the spawning season, the temperature of the water ranges from about 60° Fahrenheit to 90° Fahrenheit. The usual temperature, however, is from 60° to 81° Fahrenheit. When the temperature falls below 65° Fahrenheit the development of the embryos is greatly impeded, in fact, it almost ceases; whereas, at a temperature ranging from 74° Fahrenheit to 80° Fahrenheit it is very rapid, so that in three to ten hours from the time of the fertilization of the eggs they have advanced as far as the swimming or veliger stage, and have acquired a larval shell. Cold rains frequently kill a great deal of fry during the summer. Other meteorological disturbances, such as violent thunder-storms, have also been found to be injurious or fatal to young oyster embryos. The fifth principle to be borne in mind in successful oyster culture is, therefore, the following: *That the prevalent temperature of the water during the spawning season shall range from about 68° to 80° Fahrenheit.*

11. **Food of the fry and spat.**—The *food* of the fry, spat, and adult stages of the oyster is also an important matter. That of the fry consists of the most minute organic life to be found in sea-water, such as *Bacteria* and *Monads*.+ Many of the food balls found in the intestine of the recently attached spat will measure under $\frac{1}{10000}$th of an inch in diameter. The cavity of the little creature's stomach measures only $\frac{1}{2500}$th of an inch. Yet in this minute digestive cavity the food is actually found rotating in the form of minute rounded and oval bodies, which are kept in motion by the action of the cilia which line the stomach. That these bodies must have been of about the size noted when they were originally swallowed and as seen rotating in the stomach, is

evident from the fact that the young oysters, like the adults, are wholly without teeth or triturating organs of any kind.

This minute kind of vegetable and animal food is found more or less abundantly in all sea-water, and is especially abundant during the spawning season, when the decomposition and disintegration of all kinds of minute organic *débris* floating about in the water is in rapid progress, owing to the prevalent high temperature of the air and water. It is therefore probable that very few otherwise suitable locations exist where it is not possible to find an abundance of the proper sort of food for the oyster during its very earliest stages of growth.

12. **Food of the adults.**—The food of the slightly more advanced spat and the adults is found to consist of diatoms, rhizopods, infusoria of all kinds, monads, spores of algæ, pollen grains blown from trees and plants on shore, their own larvæ or fry, as well as that of many other mollusks, of bryozoa and minute embryos of polyps and worms, together with other fragments of animal or vegetable origin, and sometimes even minute crustaceans. In variety of food, the oyster therefore has a wide range of choice. There are also few locations otherwise well adapted which will not supply an abundance of food for the animal, which, it is to be remembered, captures and hoards millions of these minute plants and creatures in its stomach, where they are digested and incorporated into its own organization. It therefore follows that when we eat an oyster we are consuming what it required millions of the minutest organisms in the world to nourish. The oyster is consequently a sort of living storehouse for the incorporation and appropriation of the minute life of the sea, which could never be rendered tributary to the food-supply of mankind in any other way except through the action, growth, and organization of this mollusk.

13. **The value of coves.**—It is true that partially land-locked coves or inlets with narrow mouths are favorable to the production of the minute life upon which the oyster feeds, and it is in such locations that some of the finest oysters are grown. But oysters of excellent quality are also grown in deep water, as the experience of Mr. Rowe has shown.

14. **Greening.**—I formerly supposed that green-fleshed oysters were confined to beds which were located in narrow coves or inlets; in fact, there seems to be a predisposition to develop the green-fleshed condition when oysters are cultivated in ponds or *claires*. Recently I find that my original conclusion must be modified, as I have found that green-fleshed oysters are found in open water and at a depth of 4 to 5 fathoms. As already stated elsewhere, this condition is now well-known to arise from the absorption of the coloring matters in certain kinds of food which is consumed by the animal, and that the latter is in no way impaired or rendered hurtful as food. (See note X, in Appendix.)

15. ***Effects of currents.***—The effects of currents of water are also to be taken into account. When a current sweeps around a gravelly, shelly

point of the shore, and if, under these circumstances, the water be well charged with floating fry from adult oysters in the vicinity, the set of spat will often be very abundant. This is especially the case where the tidal currents are strong enough to make such points act as jetties and keep the sediment and *débris* from lodging on the cultch so as to cover it up. Such natural conditions are presented by projecting gravelly points along the shore and on the buoys in the channel near Cohasset, Mass. So constantly has it been found that oyster-spat catches or falls in abundance on the gravel at that place that oystermen were formerly in the habit of going there to obtain the gravel after it was covered with spat for seeding purposes. We actually behold here in operation, under natural conditions, processes which can be imitated on a large scale by artificial means, with such success as to make us wonder why some such method as the one presently to be proposed was never applied before.

16. **Effect of currents on fixation.**—It may be asked, however, will the young fry attach itself to a fixed collecting apparatus where the current of water is running rapidly through the latter? It might be supposed that where a rapid current was sweeping over the cultch it would have no chance to become affixed, but this is a mistake, for I have found that spat will become affixed to a stationary object just as abundantly in a current running several miles an hour as when the water is comparatively quiescent. This was also verified in the closed-circuit experiments made in 1882, when the artificially fertilized embryos were kept in constant motion. Similar results were, I believe, obtained by Brooks and Winslow in another apparatus, in which the water charged with embryos was kept continually moving. All of the facts, therefore, which have been observed both under natural and under artificial conditions, indicate that rapid movement of the water which is charged with embryos does actually in no way interfere with the fixation of the fry; on the contrary, it rather seems to favor fixation.

Currents of comparative rapidity and force do not detach the quite recently affixed fry, as has been shown by me as the result of other direct experiments and observations.

17. **Utility of artificial fertilization.**—The artificial fertilization of the eggs may also be expeditiously accomplished with certainty to the number of billions at a time, so that, besides the chances for obtaining spat from water charged with embryos by natural means, we are enabled to add greatly in favorable weather to the number already in the water. The chances to obtain spat may thus be doubled or even quadrupled by the aid of artificial methods.

18. **Causes destructive of embryos.**—Great losses of embryos are doubtless sustained under natural conditions from the circumstance that millions of billions of eggs and embryos either sink into the mud to be irrecoverably lost, or many ova are never even impregnated. Under artificial conditions these embryos may be reared to the swimming stage and

brought so far along as to diffuse themselves through large bodies of water. That such diffusion actually does take place is shown by the fact that the oysters lying at the bottom of the water at Cohasset threw off embryos which swam up through 2 fathoms of water so as to reach and adhere to the pole buoys as far as they were immersed.

19. **Conditions at Fortress Monroe.**—At Fortress Monroe the oysters which are attached so thickly to the walls of the moat are wholly derived from floating fry, and it is instructive to observe that on the muddy bottom of the moat there are neither old nor young oysters, because the conditions for their existence are not present there. Here the walls of the moat form a natural collecting surface, and as the tide ebbs and flows the conditions favorable to their existence are present, just as on natural banks the old oysters form natural cultch upon which year after year spat falls; then as the bank becomes higher and higher the tides sweep the surfaces of the shells clean and afford the spat a chance to survive, but at the expense of the life of the old oysters beneath, which are finally covered and smothered by the young growth.

20. **Nuclei of natural banks.**—As far as I have been able to discover, the nucleus of a natural bank is always some mass of cultch which existed naturally on the bottom or has been placed there intentionally or unintentionally by man. This may be illustrated by several sets of facts which have either fallen under my own observation or have been communicated to me by reliable persons. In one case a heap of shells thrown down on the bottom in Cherrystone River became the nucleus of a well-defined bank or reef in two years. In another case a dense cordon of pine brush stuck down into the bottom in Mobjack Bay became the nucleus of an oyster bank or reef. In the vicinity of New Haven brush stuck down into the river bottom, forming a dense sort of *chevaux-de-frise*, has been found a profitable type of collector.

21. **Position of natural banks.**—Natural beds or oyster reefs tend to have their long axes extend across the channel, as I have noticed in several places, and such banks also become longer and greater in area if properly worked. They tend also to become higher, so that eventually at low tide the oysters are left by the tide for several hours at a time; this is due of course to the fact that the last generation becomes the cultch for the next one. Such banks also doubtless arise upon ridges of gravel on the bottom, or are developed on gravelly shoals running out from the shore. This seems to have been the history of several which I have examined. In all, the one same set of favorable conditions seems to have been present.

22. **A firm bottom necessary.**—A fixed bottom or basis of attachment must exist where oysters are expected to thrive or develop spat. Shifting deposits of sand, mud, or ooze are always fatal if the deposit reaches any considerable thickness. A firm or hard bottom is therefore a prime condition in oyster culture. If cultch is thrown on a soft, muddy bottom, it would have been far better had the oyster culturist

allowed it to remain on shore, where it would at least not have been altogether useless. In many cases it is necessary before planting that the bottom be prepared by dumping gravelly, firm loam over it before attempting to plant either oysters or shells on it, so that it may be firm enough for the purpose. In other cases dredging might be resorted to with advantage, but that would depend upon circumstances; whether, in fact, it could be done at a justifiable cost.

23. **Spatting in narrow channels.**—Another remarkable combination of conditions under which a fall of spat occurs may be here cited in partial illustration of the system of spat-culture to be developed in the sequel. At Wood's Holl, Mass., Mr. J. S. Fay some years ago planted some oysters in almost land-locked ponds owned by him, and in which the density of the water ranges from 1.012 to 1.020. An outlet from these ponds consists of a little water-course which is not much over a foot in width and 6 to 8 inches deep at any part of its extent. In the bottom of this water-course there are a great many loose stones and pebbles, and upon these oyster fry has adhered in considerable numbers. In this case what would at first appear to be very unfavorable conditions for the adhesion and development of oyster fry are, on the contrary, found to be quite favorable.

24. **Critical periods during the spawning season.**—There are critical periods or crises during the spawning period when the larger proportion of the spatting of one season occurs. Somewhat prolonged observation indicates, as far as my personal experience goes, that these crises occur during the latter part of July and early part of August. According to the observations of Brooks and Winslow the critical period when the greatest amount of spat falls is somewhat earlier farther south, perhaps a week or ten days. In order to get the best results from the use of collectors of any form, it is therefore desirable that the cultch should be exposed to the fry at about or just before the time mentioned, otherwise the best portion of the season will be lost to the propagator. Another reason why the cultch should be put down during or immediately preceding these critical periods is that the accumulation of slime, diatoms, and sediment on the cultch is avoided during the most important part of the spatting period.

The *accumulations of diatoms on the collectors* are especially noxious and hurtful to the recently fixed fry, since, together with the hordes of microscopical, boat-shaped organisms known as diatoms, there rapidly develops a slimy, transparent pellicle on recently submerged objects which soon reaches a thickness of at least one-sixteenth of an inch. This pellicle is sometimes quite clear and transparent, like the white of an egg, and contains besides vast numbers of frustules of diatoms innumerable multitudes of still more minute organisms resembling *Bacteria*. The accumulation of this pellicle is usually only a matter of a few days, and is probably more hurtful to the very early stages of the oyster than all of its other enemies combined.

I believe, in fact, that under ordinary conditions a hundred or a thousand times more fry actually adheres than can ever reach even the condition of spat, on account of the asphyxiating effect of this coating or pellicle which rapidly develops over the surfaces to which spat is adhering.

25. Summary.—The foregoing statements of notices, principles, and of observations made, where human agency had and where it had not affected the results, must now be depended upon to yield us an answer to the question whether spat-culture will be feasible and profitable or not. I think we will be able to show that all of the methods hitherto applied were founded on a partial or total misapprehension of the essential principles which should have controlled the choice of the plans upon which the work was to proceed. Following in the wake of the French, we adopted an inefficient system of collectors, because these were too scattered to attain results of the greatest possible value, or if not too much scattered, they soon became too thickly coated with sediment in most situations to be of service as collectors. In order to remedy both of these defects, it is proposed to break away entirely from the effete and antiquated methods of Europe. The American system of sowing shells appears to be profitable, but, as already stated, the planter is not getting the benefit of the whole surface of the shells sown, besides running the risk of having them covered with sediment. *To obviate all of these difficulties, and to actually come into competition with the system of shell-sowing in deep water, we must proceed to abandon all old methods, condense our cultch so as to have the greatest possible quantity over the smallest possible area, and finally, have that so arranged that, the currents developed by the tides in consequence of the peculiar construction of a system of spawning ponds and canals will keep the cultch washed clean automatically.* Unless this can be done, all systems of pond or cove culture for the purpose of obtaining spat must unhesitatingly be pronounced failures.

The foregoing is the present status of the whole question, and, after stating as fully as I have at the outset what are the conditions, we are now ready to present the plans proposed to carry them out. In doing this we have plain, simple facts and principles to guide us, provided that we always have an abundance of floating fry and that we provide means which will direct it against or upon our cultch at the critical moment of its existence, or when it is ready to affix itself. The greatest source of loss in the culture of the oyster arises through our inability to give the billions of larval oysters which are annually wafted about by the waves resting-places where they may become manageable spat.

III.—The new methods of spat-culture.

(A) The method as adapted to canals or sluices in which the cultch is placed in masses, with jetties at intervals.

The first form in which I propose to inaugurate the new system of spat-culture which has grown out of the principles already developed, consists, essentially, in condensing the cultch or collecting apparatus in such a way as to expose the maximum amount of collecting surface for the spat to adhere to within the least possible area. This may be achieved in the following manner: A pond, *X*, as shown in plan and elevation in Plate I, is constructed with a long zigzag channel, *s*, connecting it with the open water. The pond ought to be, say, 40 to 60 feet square; the channel, *s*, may be, say, 3 feet 3 inches wide, as shown in the diagram. The vertical banks, *z*, between the zigzag canals running to the open water might be 3 feet in width. The sides of the canals ought to be nearly or quite vertical, and the earth held in place with piles and rough slabs or planks. The direct inlet to the pond at I, might be provided with a gate, and the outlet of the canal, where the latter connects with the open water at *o*, might be provided with a filter of moderately fine galvanized-wire netting and a gate—the first answering to keep out large fish and débris, and the latter to close under certain circumstances, or when violent storms develop strong breakers. The accompanying plan and sectional elevation, as shown in Plate I, will render the construction of such a pond and system of collecting canals clear.

Into the pond, *X*, I would put an abundance of spawning oysters, say 100 bushels, if the pond were 40 feet square, and 200 bushels if it were 60 feet square. But instead of throwing the oysters directly upon the bottom, I would suggest that a platform, *P*, of strong slats, be placed over the bottom of the pond at a distance of 8 to 10 inches from the earth below, upon which the oysters should be evenly distributed. This arrangement will prevent the adult oysters from being killed by sediment, and also afford a collector in the form of a layer of shells to be spread over the platform, and give the fry a better chance to escape without immediately sinking into the ooze below.

The mean depth of water in the pond and canals ought not to be less than 3½ feet, and the bottom of the pond and canals should be cut to the same level, with a view to get the full benefit of the tides.

The method of operating such a system will now be explained. The pond *X* is supplied with the above specified quantity of good spawning oysters, which at a low estimate ought at the rate of fifty females per bushel, to yield from one hundred to two hundred billions of fry during the time the cultch may be in position in the canals. If, however, the oysters were very large selected ones, fully twice as much fry ought to be thrown out by them, or fully two to four hundred billions.

This enormous quantity of embryos must, unless it finds some objects to which to attach itself, be irrecoverably lost. In order, therefore, to provide it with a nidus for the purpose of fixation, an extensive system of collectors is provided in the channel *s*. These are figured in detail on Plate II, the first being an end and the second a side view, and the third a plan. These are essentially flat baskets with wooden ends, and with the bottoms and sides formed of a very coarse kind of galvanized-iron wire netting, with 1 to 1½ inch mesh. At the top they are open, and on either side a strong strip or scantling is secured and projects out past the ends of the box or receptacle to afford a means of supporting the whole upon scantling or ledges secured near the tops of the sides of the canals *s*. These projections of the strips are also intended to afford handles by which two men may lift and move the apparatus about. The uprights at the ends and the horizontal cross-bars are intended to enable the culturist to vibrate the box and its contents in the water of the canal without lifting it out and in such a way as to wash off any injurious accumulation of sediment not swept away by the action of the jetties presently to be described.

These baskets or receptacles are open at the top and are intended to be filled with clean oyster or clam shells as cultch for the spat. They are each to hold about 3 bushels of shells, a quantity as large as can be conveniently handled by two men. One hundred of these will therefore contain 300 bushels of cultch; though I actually believe that four hundred such boxes, or 1,200 bushels of cultch through which sea-water charged with fry thrown off by 100 bushels of spawning oysters would pass would not afford too great an amount of spatting surface, because we have shown on the basis of actual observation, that a body of water adapted to oyster culture is capable of yielding spat throughout all of its three dimensions.

These boxes or frames, after they are filled with the cultch, are suspended in the canals, the cross-section of which they should nearly fill at low tide. They are placed with their widest dimension across the canal, so that during the rise and fall of the tide the water has to rush through them no less than four times daily, and as the water is thoroughly charged with embryos, the greatest possible opportunity is afforded the young fry to affix itself.

In order to still further guard against the accumulation of sediment it is proposed to place jetties across the canals, as shown in the ground plan at the points *j*. These may consist of boards, forming a frame, which may slide into or be secured by vertical ledges fastened to the sides of the canal. These jetties may have one or two wide vertical slots in them, through which the tide will be compelled to flow with augmented velocity, and thus scour the sediment off of the cultch contained in the suspended boxes or frames on either side of them. Such jetties may be placed at intervals along the canal, and they might be made movable so as to be changed in order to affect other sets of boxes of cultch at other points along the sluice.

The system of canals as shown in the plans should hold about 400 receptacles filled with shells, or at least 1,200 bushels of cultch. In practice I think it probable that even a longer system of canals will be found available, but it must always be borne in mind that the area of the pond must not very greatly exceed the total area of the system of canals, or else so much more water will run out of the pond at every ebb of the tide that a great many embryos will be carried past the system of collectors in the canals into the open water and be entirely lost. There is, consequently, a very good reason for having the areas of the two nearly equal.

The preceding system of culture, it will be obvious, is only an application of principles well established and based upon the observation of the actual behavior of oysters under natural conditions, as observed at Fortress Monroe, Saint Jerome's Creek, Wood's Holl, Cohasset, and Long Island Sound.

The spawning ponds after the season is over may be used for fattening choice oysters for market, as they will actually hold about the quantity stated at the outset of this chapter. They may also be used in connection with another modification of the method of using cultch much crowded together or condensed, to be described later on.

The cultch may, without harm to the spat, be allowed to remain in the suspended receptacles in the canals until the first or middle of October, when it should be taken out and spread upon the bottom on the open beds where it is to grow larger. The reason for allowing the cultch to remain so long in the boxes is because spatting under favorable conditions continues for not less than ninety days, or from July 1 to October 1, so that all of this plant should be in working order by the first of July.

This system is especially well adapted for the work along the Chesapeake, and I know of no better location for the construction of these new devices for spat-culture than the United States Fish Commission station at Saint Jerome's Creek, in Saint Mary's County, Maryland. At that place the equipment and conditions already in part exist for its realization at far less cost than in any other place which could be occupied by the Commission for the work at present.

(*B*) *The new method of condensed spat-culture as conducted in a series of tanks filled with cultch.*

In this modification, the sea-water, charged with an abundance of free-swimming fry, is pumped through a series of troughs filled with cultch, the method being founded on the accidental results obtained in 1881 at Cherrystone, Md.

The water from the spawning ponds, or from vats charged with artificially fertilized fry, is pumped by means of a steam-pump or a pump operated by a wind-mill, into an inclined tank, shown in elevation and in plan in Plate III. Such a tank inclined at an angle of about 15° may be 45 feet long, ten feet wide, and 1 foot deep, and may be subdivided into fifteen compartments transversely, each of which would be about 3 feet in width. The transverse subdivisions within the tank should be two or three inches lower than the sides so as to allow the water to run from the highest to the next lower one in succession, and finally into the lowest compartment, from which the water would run back into the spawning ponds, or the vats containing the embryonized water. Each of the successive compartments is filled to the water-level with cultch, preferably oyster-shells, upon which the spat will adhere. Such an apparatus, containing 180 to 200 bushels of cultch, would be as efficient as the same amount in the system of canals in connection with spawning ponds, with only the disadvantage of having to use some kind of power in order to pump the embryonized water through it instead of depending upon the tides to operate the plant automatically. It might also cost relatively somewhat more to keep in repair than the system of ponds and canals.

Taps or plugs might be arranged in the bottom of each of the compartments to draw off any accumulations of sediment which would collect in them.

Another system of tanks through which a continuous flow of embryonized water might be kept running is also submitted in elevation and in plan, in Plate IV. This consists of a series of ten troughs, *a* to *k*, which, as in the preceding system, are supported on a framework of tressels. The embryonized water, from the spawning ponds or vats, is pumped into the highest trough, *a*, and runs into a narrow compartment at one end of the tank, as shown in section in the sectional elevation. This narrow compartment opens below into a space covered by a sloping perforated partition or bottom. The cultch is placed in the trough so as to cover the perforated false bottom, and is to fill the trough evenly within half an inch of the water-level, which is determined by the height of the board at the other or outflow end of the trough where the water pours over a chute into the next trough below. The object of the perforated bottom is to cause the embryos to be distributed and be brought into contact with the under side of the shells or cultch. After the water, charged with free-swimming embryos, has passed through this chain of troughs it is returned to the spawning pond connected with a canal system, or back into the ponds or vats in which artificially fertilized embryos have been poured.

Each of the troughs of this system measures 12 feet long, 6 to 8 feet wide, and 1 foot deep. It is undesirable to make them deeper for the present, as it is doubtful if sufficient light would penetrate through a very much deeper layer of cultch. Their aggregate capacity would be from 100 to 150 bushels of cultch, or very much less than could be accommodated in the system of canals. I believe, however, that there would be more complete control. This system could be operated with great expediency at Wood's Holl, where the experiments of this year have very conclusively shown that oysters will live, thrive, and increase, some individuals from Long Island Sound having made a new growth of a quarter of an inch in the short space of a month. It is especially desirable to conduct the work of spat-culture at Wood's Holl, in the lower floors of the new laboratory and residence, where the facilities for obtaining an abundance of sea-water are unsurpassed. This is all the more easily done now that our experiments in transplanting oysters to that place have been so successful, but where they have never heretofore been to any extent indigenous.

It is also very important that the tanks or troughs be operated on an extensive scale at Saint Jerome's Creek station, in connection with the system of spawning ponds and canals containing the new system of collectors. The efforts which are to be made now, after we have so far worked out the details and principles, are simply those of routine, and it is to be hoped that no pains will be spared to push the construction of the necessary plant to completion at both places as rapidly as possible, and in abundant time for the beginning of the spawning season on the 1st of July, 1886.

The method of pumping embryonized water, or water containing oyster embryos, through shells, was resorted to by Brooks and Winslow in 1882, the apparatus used by them being still in existence among the stores of the Fish Commission at Wood's Holl. The same year McDonald's apparatus was operated, and in that adherent fry was obtained, to our delight and astonishment, 24 hours after its fertilization. In that apparatus the same body of water was constantly kept circulating by hand. In Bouchon-Brandely's apparatus the water charged with embryos was operated by means of a pump, and I think about the same time. These details are given as matters of history, in case there should be any disputes in the future as to who was the first to use such methods. Each one of these experimenters devised his apparatus independently of the other, and in ignorance of how any one of the others was working, so that there could have been no unrightful appropriation of ideas on the part of any of them.

But all of these experiments, I am now satisfied, were conducted on too meager or limited a scale to be very decisive in character, but they have served to indicate what are the proper methods to be adopted. Large quantities of cultch and large and continuous supplies of fry from large quantities of oysters were never used in any of these experiments such as it is now proposed to use in the further prosecution of the work. Whatever results we see accomplished under favorable conditions in nature can be just as readily accomplished under conditions which may be supplied by the ingenuity of the cultivator, if he is guided by the proper preliminary knowledge. If any one were to inform me that I could not produce even more satisfactory results in collecting spat than are to be seen occurring naturally in the moat at Fortress Monroe, I would simply tell that person that he knew nothing of the conditions determining the nature of the problem which he pretended to regard as incapable of solution.

What we must do to-day is to adapt such means to the solution of the oyster problem as will render them applicable in practice. The American cultivator does not get the price obtained by the French or Dutch oyster farmer, nor can he for a long time to come expect to, for the reason that the aggregate area upon which the American oyster is cultivated or indigenous exceeds by many times that upon which the European species is either native or cultivated. The European methods of using cultch, such as tiles, slates, brush, fagots, &c., are too expensive, too elaborate, for our practical people. We must reap in quantity what they reap out of the high price of their product. Under the circumstances there is no possible way of solving the greatest question which now exercises the oyster-growers of this country, but to put into their hands a method by the aid of which they can get all the spat they want on their *own* lands and from the spawn of their *own* oysters.

This we propose to accomplish with the apparatus described above. The cost of the entire plant requisite is a mere trifle compared with the results to be gained by its use. In order to show that the method is practical, I will state some of the results of previous experiments with collectors at Saint Jerome's Creek in 1880. I arrived there on the 19th day of July in that year, and on the 22d of the same month had some collectors in place in the open water and coves. I continued to put out collectors until towards the middle of September, but in nearly every case it was impossible to direct the water charged with embryos directly upon the collectors as it is proposed to do by the help of the new method, yet in almost every case I obtained a set of spat on these collectors, some of the young oysters on the latter by the first of November measured nearly two inches in length. It was then that I first noticed the disposition of the spat to adhere to the under or clean side of the cultch and also to surfaces which were vertical and their indisposition to adhere to the dirty upper surfaces of the slates, &c., which were used.

Enough spat was obtained that season to prove that it could be profitably collected in that way provided we had a sufficiency of such within a limited area so as to condense our cultch and get more spat on a smaller area. Many of our collectors during that season soon became heavily coated above with sediment (as much as an inch in depth being deposited in two months), so that such surfaces were rendered valueless for our purpose. Had we instead been able to expose one hundred times as much collecting surface within one tenth the space covered by the apparatus used that season, the oyster question would have been settled that year. The subsequent experiences which were obtained there and at other places, however, have served to indicate that still other supplemental conditions were necessary, viz, (1) such that would enable us to direct the water charged with embryos direct upon the cultch, and (2) such a utilization of the tide and construction of the receptacles for the cultch as would enable us to keep the latter clean.

In order to realize the spat-yielding capabilities of any given body of water to its fullest extent, and throughout its three dimensions of length, breadth, and depth, the cultch must be distributed as evenly throughout those same three dimensions as possible. This implies the concentration or condensation of the cultch or collecting apparatus to an extent never before attempted. The new method here proposed will then mark the third period or stage of the development of oyster culture. The first one is the *laissez-faire* stage of the industry, now largely prevalent in this country. The second stage is the ordinary method of shell-sowing.

The advantages of the method of using the cultch in concentrated bodies, giving an enormous amount of surface for the spat to adhere to, are, that it can be conducted on the land owned by the culturist himself, and with the spawn thrown off by the oysters belonging to him. He is therefore not bound by any arbitrary oyster laws now existing to conform to what are, generally speaking, very inefficient and often absurd conditions. The new method puts it in the power of the culturist to rear his own seed for planting, and if he is so disposed he may put down an excess of cultch, which he can sell after it is covered with spat to the owners of the open beds in his vicinity. It involves comparatively little outlay to put down a plant which will accommodate 5,000 bushels of cultch, or enough to seed from 20 to 30 acres for the first year. Such a system would be of great practical utility in the region of the Chesapeake Bay, where there are very extensive areas upon which, with very inexpensive excavation, the plant for conducting this method of culture could be organized.

At places like Wood's Holl it would also be possible to organize the system of using the cultch in concentrated form, so that if the locality did not actually afford the means of extensive bed-culture for market, it would in many instances become available for the purpose of rearing spat to be planted in available localities near by.

IV.—THE FUNCTION OF ARTIFICIAL FERTILIZATION.

As stated in the introductory portion of this paper, the utility of artificial fertilization of the eggs of the oyster is unquestionable, but I would not give it either the principal, nor yet a subordinate place in my system of spat-culture. We know, for example, that 100 bushels of good oysters ought to yield at least 100 billions of fry. While we cannot possibly prevent a very large percentage of this astounding yield of embryos from being lost, it would be very poor economy indeed not to avail ourselves of such a convenient and constant source from which to obtain embryos under natural conditions. So I propose that we use the natural yield thrown off by the adult oysters, but in addition call in the aid of artificial fertilization to supplement the supply of fry yielded naturally.

Into the spawning ponds and system of canals, in which the cultch is suspended, the tide will ebb twice and flow twice every day. In other words, the water charged with embryos is changed over the collectors four times in every twenty-four hours. During ninety days, or as long as the spatting season lasts, the water surrounding the collectors will have been changed or shifted about 360 times. During the ebb tide the fry will be carried out of the pond into the canal, and thrown into contact with the collectors twice daily. When the flood tide again returns the water to the pond from the open bay a large part of the fry will be carried back into the pond again, and away from the cultch or collectors. It is during the flood-tide that I would therefore commend the practice of putting artificially-fertilized embryos in the swimming stage of development into the outlet of the canal to be swept back amongst the collectors toward the spawning pond.

The artificially-fertilized embryos should be taken from the adults by gentle pressure with a pipette and dropped into a dish of clean sea-water so as to discover by means of the "drop test," when male and female products were obtained so as to make sure of artificial fertilization. In a favorable temperature and suitable weather they will reach the swimming stage in three or four hours, when they may be poured into the canal system, or into the spawning vats or ponds used in connection with the troughs filled with cultch through which embryonized water is being pumped. This is an important point, as the chances for the adhesion and survival of the fry after it reaches the swimming stage are very greatly increased.

Another way of providing fry in the canal at all times would be to place a half-dozen good spawning oysters in every receptacle for cultch so that an abundance of embryos would be constantly wafted back and forth in the canal. Even then I think it would be advisable to use artificially-fertilized spawn as supplementary to that thrown off in addition from the oysters contained in the receptacles filled with cultch. This would render the operator trebly sure of results. The importance of artificial fertilization is shown by the facts established as a result of the experiments with ponds, into which and out of which the water passed through filters of sand, at Stockton in 1883, and at Saint Jerome's Creek in 1884 and 1885. As the spat obtained in these ponds was entirely derived from fry which had been artificially fertilized, there can be no doubt of the efficiency of artificial fertilization.

V.—COATING THE CULTCH WITH A DETACHABLE COVERING OF LIME OR CEMENT.

Coating the cultch with a layer of lime and sand, or lime, cement, and sand, cement alone, or cement in combination with various other substances, such as ox-blood, as proposed by Dr. Kemmerer, may serve an excellent purpose, and might even be necessary where the spat became so thickly crowded together as to be killed as a consequence of overcrowding. Under ordinary circumstances, however, where only one or two young oysters adhere to a single shell, there would be no need for any such detachable coating, as there would be no danger from overcrowding. Nevertheless, where as many as fifty or one hundred spat become attached to a single shell such a coating would probably be found necessary, as under such circumstances it would simply be impossible for any but a small proportion of the entire set to survive beyond a month or so. In case such overcrowding should occur on the cultch used in the collectors employed in the canals or troughs, it would probably be best to use a coating of some kind on the shells.

Such a coating should consist of a very thin mixture of very fine sand, lime, and a little cement in such proportions as will cause the coating to set firmly and not wash off readily, but be easily flaked off with a little effort, so as to free the crowded spat. Into such a mixture the shells used as cultch might be dipped very rapidly by means of a basket of wire netting, so that half a bushel could be coated at one operation, the surplus mixture shaken off, and the shells thrown into a heap to allow the coating to set preparatory to being thrown into the troughs or the receptacles used in the canal system. For filling the latter a wooden hopper provided to fit over the top of the receptacle, and removable so as to be used in filling collectors successively, would be useful, as the mouth or open top is rather narrow to admit of a shovelful of shells being conveniently thrown into it.

In handling the spat which has been flaked off of the cultch when overcrowded, wider and more capacious receptacles, made of finer galvanized wire netting, and constructed upon the same general plan as those used to hold the cultch in the canals, might be made to receive the detached spat. These could then be suspended in the canals and allowed to remain there until a year old, when they could be scattered upon a firm, clean bottom to grow larger. In this way the canal system could be kept in use a great part of the year, or until the next spatting season.

VI.—COLLECTORS.

In handling tile and slate it must always be coated with a detachable covering of lime and sand, or something of the kind, in order that it may be possible to remove the adherent spat. After that the individual tiles and slates must be supported by some sort of framework, or fastened together in some sort of a bundle to make them most effective. The result is that the first cost of such collectors is too great, because both the tiles and slates must be bought as manufactured articles, whereas the shells can be got for the trouble of hauling them away, in the region of the Chesapeake at least. Moreover, the cost of the contrivances for supporting the slates and tiles, together with the latter, is almost as great in the long run as that of the receptacles in which the cultch is suspended in my system. These receptacles, being for the most part constructed of galvanized wire-netting, will last for at least three or four years, during which time each one of them should have produced at least 9 to 12 bushels of spat suitable for seeding purposes. The new apparatus can be used repeatedly, whereas the other, if it is used again, must be recoated, and if made of several tiles or slates must be reconstructed every year. All of these disadvantages render the older European methods so cumbersome and expensive that they are of very little service in this country, where it is desired to get the largest possible return for the least possible outlay both in labor and money.

I would therefore unhesitatingly give the preference to oyster-shells as cultch, especially since they can still be obtained far more cheaply than either tiles or slates. The time may come, however, when these may become so valuable as cultch that it may be necessary to find some substitute. In that event potsherds might be manufactured on a large scale to answer the purpose equally well. Pottery—such as is used to make clay pigeons for sportsmen—would be very serviceable as a collector. Clay pigeons, in fact, either entire or broken up, would make an excellent kind of cultch.

A curious property of oyster-shells, manifested where they are simply sown on the bottom, and which has fallen under my observation, is of considerable interest in connection with oyster culture. It is found that if the dead valves of the oyster are thrown into water they will almost invariably fall to the bottom with the smooth inner or concave face upward, and the rough convex face downward. The best side is therefore, in the practice of shell-sowing, the least efficient for the purpose of collecting spat. Upon investigation this is found to be actually so not only when oyster-shells are sown as cultch, but also when those of the clam and scallop are used for the same purpose. Upon examining the shells used as cultch by the Long Island planters it will be found that the most of the spat has adhered to the convex or undermost side of the shells, and that comparatively little spat has fastened itself to the upper side.

When the oysters are planted in the water from a boat, they also, as a rule, fall upon the bottom with the left or most convex and colorless valve downward, while the colored and flattest or right valve is uppermost. Upon examining old oysters which have been lying flat on the bottom the spat will be found for the most part fast to the lower valve, just as we found it upon examining the cultch of shells.

These data seem to me to indicate most conclusively that the sediment which is deposited from the overlying water has rendered the upper surfaces of both the cultch and the oysters unfit for the adhesion of young fry. That it does adhere to the upper surface very often we have evidence enough, but we also have abundant evidence to prove that it adheres there far less commonly than to the lower side. So we actually find that the experience with slate and tile collectors in shallow water tallies completely with what is observed in relation to the cultch used in deep water, namely, that the lower side is always the most efficient for the purpose of collecting spat. This leads to the obvious conclusion that in suspending our masses of cultch above the bottom we are doing the very best possible thing to facilitate the adhesion of the fry and prevent its subsequent asphyxiation by the accumulation of sediment.

This sediment needs some discussion, so as to point out to the reader something in regard to its origin. Observation has taught the writer that it is largely of organic origin; *that it in fact is largely composed of* seaweed, in sounds and along shore, which has been torn loose and ground into fragments by the action of the breakers and undertow, as it is always increased in quantity during storms. Wherever there are coves or inlets this fine *débris* is carried into them by the flood-tides, and during slack-water it is slowly deposited by the action of gravity. I know of localities where deposits of ooze exist which owe *their origin* entirely to such a *slow deposition of sediment*, and where it is now all of 10 feet in thickness. Such a bottom is, of course, quite unfit for purposes of oyster-culture, and is just as totally useless if it is intended to sow cultch. If the cultch is suspended or supported above the bottom, then it is possible to obtain spat in such situations, as the writer has found by actual experience.

Other materials, such as gravel, under some circumstances, might be advantageously used as cultch, but ordinarily I suspect that unless it was sown on very firm or hard bottom, after being taken from the suspended collectors in the canal system, many of the young oysters would be smothered. It would also present less collecting surface in proportion to its weight than shells.

Hard-wood chips made by the wood-cutter's ax, after becoming waterlogged, might serve as *cultch if* placed in the suspended collectors, but as the slow decomposition of the wood is unfavorable, I doubt if anything would be gained by its use which would not be just as effectually achieved with the use of shells.

In fact, after considering all the readily available materials, I do not think there is anything which can be compared for suitableness and efficiency with oyster, clam, or scallop shells as cultch. There is certainly no form of collector in use in Europe which will as cheaply afford the same great amount of spatting surface as can be obtained in suspended receptacles filled with shells such as are used in the canal system here proposed.

It appears to me that stringing shells upon wire is also impracticable in this country. That involves taking each shell singly and perforating it before it is strung. Such a proceeding might answer very well where labor costs one-third of what it does in the United States. If we can suspend the shells just as effectively and at far less cost without handling them singly in order to perforate them, it would indeed seem to be a waste of time and labor to resort to such an expensive method to effect what can be done far more easily and on a larger scale in another way.

VII.—The possibilities of the new method in the hands of the oystermen.

I know perfectly well how this paper will be greeted by the conservative oystermen. I find, indeed, that even those who pretend to be scientific are ready to cavil at the attacks here made upon the present systems and the apparently extravagant claims to which I have given expression. After five years of careful and often laborious observation and study, during which time I have personally instituted a large number of experiments in the field, and have studied the problem in all its aspects, I am ready to own that I have misapprehended the very elements of the question at issue. I have taken it for granted that the methods in vogue in Europe were somehow applicable here. So they are, but not until so modified as to have lost almost all original semblance of themselves. I have *not* dealt with *probabilities*, but with *actual possibilities*, in this paper, as founded upon *personally observed facts*. I have proposed no cunningly-devised hypotheses to entrap the unwary novice, but at every step in the development of my system I have checked what I had to say upon a given point by something within the bounds of experience. This is my final contribution to the *theory of oyster culture*, a thing which it has never possessed before in the way in which it is presented here.

In no part of this paper has there been any direct reference to the anatomy or development of the animal. The practical man has no time to waste upon that part of the subject. What he wants to know is not how the egg of the oyster segments and develops, but what the habits of the minute creature are when it is first let loose in what must seem to it, if conscious, a truly vast universe of water. Moving about in its element with the help of the fine cilia encircling its velum, it swims until it finally meets with a nidus to which it can glue itself fast with the margin of the left lobe of its tiny mantle. Once fixed, its wandering existence is forever at an end. It is now ready, by slow stages of growth, to become more and more like its parent. Its shell, before and some time after fixation, is perfectly symmetrical, like that of the hard clam, and remains so until it attains the still diminutive size of one-ninetieth of an inch across. It is this symmetrical phase of its infant or embryonic career which constitutes the most critical stage of the creature's life. The losses prior to fixation are very great, and all we can possibly do to diminish them, in the present state of our knowledge, is to so enormously increase the proportional amount of cultch, to which fixation is possible, that for any given bed such losses will be reduced to their possible minimum. Scattered cultch, such as tiles, slates, &c., have been as unphilosophically and unscientifically applied hitherto as the cultch used on the bottom in only two dimensions of space. For the present mode of use of the latter, however, there are assignable reasons when such cultch is applied in open water. The use of cultch where the adult oysters are much scattered, so that the embryos are diffused through such enormous bodies of water that the greatest possible results are not obtained, is likewise unscientific. What has been needed is a study of the habits of the animal, and then to *create* the necessary favorable conditions by artificial means. I have sought to point out the way in which these conditions are to be created, and, in the hope that they may soon be extensively taken advantage of, I will turn for a moment to a consideration of the possibilities of the new method.

With the new method it is possible to provide and expose not less than fifty times the amount of spatting surface per acre that can be exposed if shells are simply thrown down upon the bottom. The yield of spat or seed oysters per acre can therefore be augmented in just the proportion in which the quantity of cultch over a given area is increased. If it is objected that the great increase in the number of oysters would rob the water of its lime in the form of its carbonates, I can reply, it seems to me, with considerable confidence, that the vast amount of oyster-shells used as cultch in the collectors would supply all that is needed in the most available form, for these shells are being constantly eroded by the solvent action of the water, so that an abundance of calcic carbonate would be supplied in solution in the water for the purpose of building the shells of the young spat. We therefore have, in these circumstances, a very strong argument in favor of the use of oyster-shells as cultch, though it may be said that coating the cultch with lime or cement would supply the shelly matter perhaps equally well.

In the next place, the culturist of limited means, if possessed of low land adjoining the shore, can organize and equip a small plant adapted for collecting the spat from a few hundred bushels of oysters at a small cost. He can not only in that way obtain the seed needed for planting upon his own beds, but also supply his neighbors at a fixed rate per bushel, with spat for planting upon their beds.

For large operations the plant would have to be proportionally extensive and costly. For a plant which would accommodate fifty to one hundred thousand bushels of shells annually, the original outlay would be very considerable.

For such operations joint-stock companies could be organized, with an assurance that great profits could be reaped from the enterprise.

In all of this work, especially where the fry from coves is utilized, we would simply be saving what is now an almost total loss to the planters over a large part of the ground at present cultivated in the old way. We would simply be saving the brood from our own beds from being swept out by the tides and irrecoverably lost.

Localities exist all along the Chesapeake Bay where this method could be utilized very successfully. The range of its applicability extends, in fact, from some distance north of the mouth of the Potomac, south, almost to Norfolk, Va. There are localities in which it is doubtful if the tides rise high enough, but wherever a tidal rise and fall of 12 inches exists, it would seem that the method could be rendered available. Tides of at least 10 to 12 inches are necessary in order to waft the fry back and forth in the canals, and to render the operation of the jetties in the canals effective.

VIII.—MODIFICATIONS OF THE NEW SYSTEM WHERE NATURAL COVES OR PONDS EXIST.

The plan of the small establishment given in the preceding pages is to be regarded as typical. In the use of the system with crowded or condensed cultch in different localities, modifications of the typical plan may often be advantageously employed. For example, an oyster planter may have a large pond of two or three acres thickly planted with spawning oysters and connected with the open water by way of a narrow canal. The pond, if it has a firm bottom over its whole extent, may, if not already used for the purpose, be planted throughout with good seed or "plants," which, in the course of two years, will be mostly well grown, marketable oysters. In such a case several systems of canals could be fed from the single large inclosure, that is to say, instead of having only a single canal, several zigzag canal systems, each 3 feet in width, might be made to carry the water flowing in and out of the large inclosure instead of the original channel, which might then be filled up and closed. Or, if it were practicable, the channel connecting the natural pond with the open water might be utilized for the same purpose as artificially constructed canals, provided the cost of modifying it for the purpose were not too great. In some cases, by digging, filling, and dredging, as might be indicated in the course of such a natural channel, it could be prepared for the reception of cultch. Where such a channel were wide enough a system of parallel rows of light piles, the rows being 3 feet 3 inches apart, and running lengthwise throughout the course of the channel, might be used to support the receptacles for the cultch, the latter being of the form used in the design of the typical system, and supported as in the latter, upon ledges or scantling spiked horizontally to the rows of piles just below the level of low tide.

In other cases where there existed narrow points in the course of such a canal these might be used as jetties, still further narrowed in some cases, perhaps by filling in the sides, after which a system of parallel rows of piles with their horizontal supports of scantling might be constructed between the jetties, and upon which the receptacles filled with cultch could be supported. In this way the fry now discharged by spawning oysters from coves through their outlets, sometimes by the thousands of billions annually, can be caught upon cultch and permitted to develop into available spat.

In many cases the cost of digging out the proper channels or canals to be used in the system of applying the cultch in concentrated form, would be greatly diminished by the nature of the ground upon which the canals were dug out. If the level of the earth is not much above that of high water, so much the better, for then the labor to be expended in making the necessary excavations will be proportionally diminished, and no assistance from a skilled engineer will be required.

Whether the spawning pond is excavated or not, the principle upon which the system is constructed and operated remains the same, namely, that the area of the canal systems and the ponds be about the same. In order that the fry may not be carried past the collectors, the area of the pond should not much exceed the total area of the canals. In order that the fry may be wafted to the outermost collectors, the area of the canal system ought not to greatly exceed that of the pond or ponds.

Canals constructed between a series of spawning ponds may also be utilized; in fact a great many other modifications of the system are available, which would become apparent only after a study of a given location. The plans for carrying out this system would in fact have to conform to the demands of the location, so that it may be said that each establishment would have to be designed in conformity with local conditions.

IX.—Convenience and accessibility of the system at all stages of the work.

No system of spat collecting with which I am acquainted can be so conveniently conducted as this one. The cultch at every stage of its exposure is completely under control. The cultch, with its catch or set of spat, can be watched and conveniently overhauled without the use of boats, dredges, tongs, or rakes. If no set of spat should happen to fall upon a part of the cultch, that portion is not out of reach, as a great part of it would be were it simply strewn upon the bottom. In the latter case, if the cultch is wanted, or if it is desired to make it again available somewhere else, it must be fished up. In my system every 3 bushels of cultch is completely independent of all the rest, and can be removed from the canal and examined at any stage of its exposure to the floating fry.

The filled receptacles can be wheeled with barrows to the canals, where they can be rapidly put in position, where they are to remain for ninety days. If all of the shells should not have spat attached at the end of that time, those which have no set upon them can be thrown aside to be used over again, and the others taken in wheelbarrows to the boats, from which they are at once scattered upon new beds as seed.

Should any collector full of cultch get out of order, it can be readily examined, removed, and repaired. There is no need of getting into an unsteady boat to go out to lift an unwieldy collector out of the water. Filling, emptying, and caring for the collectors is entirely conducted on shore in the use of the new system. Operating and handling them is in like manner done while the manipulator stands on the banks and on a sure footing, such as he sadly feels the want of while handling the heavy old-fashioned collectors from a cranky boat.

X.—SIZE, FORM, POSITION, AND METHOD OF HANDLING THE RECEPTACLES FOR CULTCH.

The size of the suspended receptacles for the cultch should not be much over the dimensions now to be given. If the vertical end pieces are 6 feet long and 6 inches wide, and secured together about the middle and parallel by broad side strips and one at top, as shown in the figures, so as to be 3 feet apart, with the wire screen inclosing the space between the end pieces or strips and below the parallel horizontal bars, a flat basket or crate is formed. This basket or receptacle is filled to the lower edge of the horizontal strips with clean oyster-shells. The contents of one of these receptacles would then be equal to 3 bushels and nearly a peck of shells, or a quantity which will be found to be about as heavy as two men can readily lift about. The receptacle when made of the size given will hold 6,936 cubic inches. There are 2,150 cubic inches in a bushel.

The galvanized-wire netting should be fastened to the sides and edges and lower ends of the vertical strips and horizontal cross-bars, with small barbed galvanized-iron staples used as nails. If, upon filling this wire basket with shells, there should be any tendency of the wire netting to "bag" or bulge outward in the middle, that trouble may be remedied by securing the central part of one side to that of the other by a galvanized wire running across the interval between them. The total cost of each one of these baskets should not be over 50 to 70 cents when made in quantity. In ordinary spatting seasons the receptacles should pay for themselves within fifteen months; that is, they should yield a sufficient quantity of spat or seed oysters at a fair market value, in that space of time, to pay for the cost of the rearing apparatus. The galvanized netting will last for fully four seasons. The wooden ends will be attacked more or less by the *teredo* or ship-worm, though it is believed that under ordinary conditions this will not be so serious an enemy to the durability of the apparatus as might at first be supposed. Copper paint might be applied as a protection against this enemy. The outside dimensions of the immersed portions of the collectors or receptacles will therefore be about 3 feet by 3 feet, with a thickness of 6 inches. This will make it necessary for the ditch to be about 2 or 3 inches wider than the receptacles below the ends of the horizontal strips. The ledge or sill on the tops of the piles, along the sides of the canal, would make the latter a foot wider at its upper than at its lower portion for about 12 to 16 inches from the top. This ledge is the simplest arrangement which can be devised to support the receptacle.

The receptacles filled with cultch are then placed with their widest dimensions across the canal, so that at every ebb and flood tide the floating oyster fry carried out and in, or from and to the spawning pond, will be driven through these masses of cultch; it is therefore desirable that just as little unused or free space in the canals be left for the water to ebb and flow through as possible.

It is not advisable to make the receptacles much thicker than 6 inches through their least diameters, lest the light necessary for the development of the spat be shut out too completely, or so as to interfere with the growth of the infant oysters. In order that the light may penetrate from above and down between the receptacles for the cultch, they should be placed 6 inches apart in the canals.

It follows from what has just been said that every running foot of the canal will accommodate three bushels of cultch. For 1,000 bushels of cultch it would, therefore, require a canal about 335 feet in length, covering a total area of only 2,010 square feet of surface, including the banks between the canals. The spawning pond to feed such a canal would be about 45 feet square, so that the whole plant would cover a total area of 4,035 square feet, including the system of canals, or not quite one-tenth of an acre. At this rate it is possible to accommodate 10,000 bushels of cultch per acre by the adoption of the new system. Fifteen hundred bushels of shells per acre would quite effectually cover the bottom, so that the ground would be concealed by them, but even that is probably a quantity which would be very wastefully applied if merely strewn on the bottom as cultch.

The care of the cultch in the receptacles is a very important matter during the spatting season. The empty space left between the receptacles, allowing 1 foot of the horizontal extent of the canal to each one, would be about 6 inches. This space, besides admitting the light, will enable the attendants to vibrate or rock the receptacles back and forth on the projecting ends of the horizontal strips, by means of the cross-bar at the top of the device. By rocking the receptacle back and forth vigorously a few times every two or three days, or even every day, the shells will be kept free from sediment, and the asphyxiation of the recently affixed fry prevented to an extent which is altogether impracticable in any other system now in vogue. This is one of the most important and distinctive features of my system, and one which will commend the latter to the favorable consideration of any one who has ever seriously considered the oyster question.

In filling the receptacles with cultch I have previously recommended the use of a removable hopper, in order to facilitate and expedite that part of the work. There is another point in the use of these contrivances which I have not touched upon, however, and it may be well to say a few words as to *how* the shells are to be placed in the receptacles.

As stated in the preceding pages, oyster-shells, if thrown into the water, will almost invariably fall with the rough convex side down, and the smooth concave side upward. This happens even when they are allowed to drop from a height into water only 6 inches deep. It also follows that if old shells are used as collectors, as proposed in my new system, there will be a tendency for the spat to catch all over both surfaces instead of only on the lower surface when simply strewn over the bottom. It will also be found that when the shells with adherent spat are taken from the receptacles used in my system and strewn over the bottom when planted, that they will tend to fall with the convex side down and the concave side up. It is obvious, therefore, that the collectors should be filled in such a way as to cause the shells to drop into them in the position which they would naturally tend to assume when sown as cultch. Otherwise it will readily be seen that in planting or sowing, the cultch covered with spat, which we have taken so much pains to rear in the receptacles, will fall on the bottom in such a way as to bury many of the young oysters. In order to avoid this as far as possible, I would recommend that the wire receptacles be placed in the water in their proper position and then be slowly filled with the shells. If this is carefully done the shells will fall to the bottom of the wire basket and assume just the same position, in relation to their surroundings as if thrown into the open water and allowed to fall to the bottom, namely, with the concave side upward and the convex one downward. The shells may now be said to have assumed their normal position in the receptacle. The latter is now ready to be placed in position in the canal.

One word about the way in which the receptacles freighted with cultch may be expeditiously handled. It will probably be found that a small, portable tripod so arranged as to straddle the canals would greatly lighten the labor of handling the receptacles. This, if supplemented by a system of pulleys over which a rope was passed, or a "block and fall," and the whole hitched to the apex of the tripod, would greatly facilitate lifting the wire receptacles in and out of the canal. Four short chains or ropes with hooks to catch under the edges of the horizontal strips would be the most convenient tackle with which to lift the receptacles and raise them out of and lower them into the canal.

XI.—Conclusion.

If cultch in the form of shells is the best (for which conclusion we have assigned reasons), it follows that such material should be so utilized as to obtain the largest possible return for the least possible outlay. In other words, if shell-cultch is to be used at all, let it be expeditiously and economically, and not wastefully and unscientifically, employed. It has been found that even the sowing of shells is profitable, as has been conclusively demonstrated, and in one type of culture, namely, that which is practiced in deep water, it is probable that it is the only practicable method which will be devised for a long time to come. While it is to a great extent wasteful and at times uncertain, for the present, at least, there seems to be no other which can be as economically and successfully operated over large open navigable areas. Large areas operated by one individual or corporation cannot always be commanded, or only exceptionally, under the existing laws of the States of Maryland and Virginia. In those States, however, where it is possible to command the right to natural areas of water which are more or less nearly land-locked, the system of merely sowing shells would be positively wasteful and not in conformity with the results attainable under the guidance of the proper knowledge. It is found in the practice of shell-sowing that extensive areas will sometimes fail to produce any spat. This is apparently due to the presence of currents which have swept the fry off the beds, or to the presence of sediment, which has put an end to the first stages of its fixed career. Even after the spat is caught, great destruction may occur through the inroads of star-fishes, or a too rapid multiplication of worm-tubes over the cultch and spat. The latter is sometimes smothered in vast numbers from the last-mentioned cause, as has been recently discovered by Mr. Rowe. Such casualties are rendered either impossible or readily observable during their early stages by the method of inclosing the cultch in suspended receptacles, as suggested in this paper. The netting will effectually protect the young spat against the attacks of large star-fishes, and no growth of barnacles or tunicates, worm-tubes or sponges, would be rapid enough during the spatting period, judging from an experience extending through several seasons, to seriously impair the spatting capacity of the cultch used in the suspended receptacles. Any of the larger carnivorous mollusks, fishes, or crustaceans which could prey on the young oysters can also be barred out and kept from committing serious depredations by means of the netting around the cultch, as well as by means of screens placed at the mouth of the canal.

The maximum efficiency of the cultch is not realized in any of the old forms of collectors, for the reason that the cultch cannot be kept clean; secondly, because both sides of the cultch cannot be exposed to the passing fry; thirdly, because the fry cannot be compelled to pass over and amongst the cultch repeatedly; fourthly, because the cultch is scattered over too great an area and throughout only two dimensions of a body of water, namely, its horizontal extent, whereas it is possible, as I have shown above, to do all this and more—that is, to avail ourselves of the possibility of obtaining spat throughout the three dimensions of a body of water charged with embryo oysters in their veliger condition. These are good and sufficient reasons for my assertion that cultch has hitherto been wastefully and unscientifically applied. With this I must conclude this exposition of the principles of a rational theory of oyster culture, a subject which has received the attention of many investigators, none of whom have, however, struck at the root of the question and allowed themselves to be guided by readily-verifiable facts. In the hope that I have made both the theory and practice of my new method clear to the reader, who, if he should happen to be an oyster-man, will, I hope, at least give me the credit of being honest and sincere in my intentions, and, whether he feels inclined to ridicule or to adopt my conclusions, I feel very certain that what I have formulated in the preceding pages will become the recognized doctrine of the future.

WOOD'S HOLL, MASS., *September* 20, 1885.

APPENDIX.

I. Since the preceding paper was written, Prof. W. K. Brooks has discussed the feasibility of using a cultch of shells in mass or quantity,* as contemplated in the system devised by me and described above. I take the liberty of reproducing Professor Brooks's note entire, as follows:

"Without expressing any opinion as to the value of the process of 'fattening' oysters by placing them for a few days in cars floating in fresh water, I wish to point out that there is no similarity between this process and the process of propagation which is here described.

"My attention was first called to the value of floating cars in oyster culture by Mr. William Armstrong, of Hampton, Va., who informed me, in 1884, that 'seed' oysters which he had placed in floating cars in the mouth of Hampton Creek grew more rapidly and were of better shape and more marketable than those which grew from seed planted on the bottom in the usual way.

"One of the results of my study in 1879 of the development of the oyster was the discovery that there is a period of several hours, immediately after the embryo acquires its locomotor cilia, when it swims at the surface, and this is the period when it is swept into contact with collectors. As soon as the shell appears, the larva is dragged down by its weight, and either settles to the bottom and dies, or swims for a time near the bottom. The tendency to swim at the surface is an adaptation for securing wide distribution by means of the winds and currents which sweep the young oysters against solid bodies which may serve for attachment. The greatest danger to which the oyster is exposed at any part of its life is that it may not, at the swimming stage, find a clean, hard surface for attachment.

"As it is microscopic and only about half as thick as a sheet of thin paper, it may be smothered by a deposit of sediment or mud so slight as to be invisible, and most of the failures to get a good 'set of spat' are due to the formation of a coat of sediment upon the collectors before the young oysters come into contact with them.

"It occurred to me this summer that this danger could be entirely avoided by the use of floating collectors, for little sediment can fall on a body which is close to the surface of the water, and most of this will

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* On the artificial propagation and cultivation of oysters in floats. Johns Hopkins University Circulars, Vol. V, No. 43, p. 10, October 21, 1885.

be swept away by currents, which will, at the same time, sweep the swimming embryos down into the collector, and thus insure an early, abundant, and successful 'set.'

"I accordingly constructed a floating car, made so as to permit the free circulation of the water. This was filled with clean oyster-shells and moored in the channel in front of the laboratory at Beaufort, N. C., on July 4. As all the oysters in the vicinity were in very shallow water, they were nearly through spawning, and the conditions were therefore very unfavorable; but notwithstanding this, I immediately secured a good 'set,' and the young oysters grew with remarkable rapidity, on account of the abundant supply of food and fresh water which gained ready access to all of them, and the uniform temperature which was secured by the constant change of water.

"This method of oyster culture may be applied in many ways, of which the most obvious is the production of seed oysters for planting.

"The seed which is used for planting in Maryland and Virginia, as well as in Delaware and farther north, is now procured from the natural beds of our waters by tonging or dredging, and as the demand for oysters for this purpose is certainly one of the elements which have led to the depletion of our beds, there is a wide-spread feeling that the exportation of seed should be prohibited.

"By a small investment of capital in floating collectors any one on tide-water could easily raise large quantities of much better, cleaner seed than that which is now procured from the natural beds, and if the laws permitted the sale and transportation of this seed without restriction at the season when the demand exists, it could be sold at a profit for less than the cost of tonging.

"Northern planters could also raise seed for themselves by constructing floating collectors in the warm water of the sounds of Virginia and North Carolina, where the length of the summer would permit several collections to be made in one season. The oysters thus reared are large enough for planting in five or six weeks, and in the latitude of Beaufort there is an abundance of spat from the middle of April to the first of July, and it can be collected until September.

"The method may also be used by planters for collecting their own seed, especially in regions remote from a natural supply. If there are no oysters near to furnish the eggs, a few spawning oysters may be placed among the shells in the collector, after the French method, to supply the 'set.'

"It can also be used for the direct production of marketable oysters, especially over muddy bottoms and in regions where public sentiment does not permit any private ownership of the bottom.

"As food for the oyster is most abundant at the mouths of muddy creeks, where the bottom is too soft for oyster culture by planting or by shelling, this method will have especial advantage in such places, for there will be no danger of sanding or of smothering by mud at the surface, and there is no limit to the number of oysters which can thus be grown on a given area, for the free current of water will bring food to them all.

"The very rapid growth will more than compensate for the cost of the floats, and Mr. Armstrong's experiment shows that, in addition to all these advantages, the oysters are of a better shape, with better shells and more marketable, than those grown at the same place on the bottom.

"Finally, this method will do away with the necessity for a title to the bottom, and will thus enable a few enterprising men to set the example of oyster culture, and, by the education of the community, to hasten the time when wiser laws will render our natural advantages available for the benefit of our people.

"The most economical method of constructing floats must, of course, be determined by practical experiments, but a float constructed by connecting two old ship masts together by string-pieces, with a bottom of coarse galvanized-iron netting, would have sufficient buoyancy and enough resistance to water to support a large quantity of submerged shells and oysters for two or more seasons, and a coating of copper paint each year would protect the timbers from worms.

"The floats should be open at the ends to permit free circulation, and they should be moored in such a way as to swing with the current.

"Engagement in business projects is no part of the office of a university, and I feel that the experiments of the past summer have brought the subject of oyster culture to a point where its further development should be left to the people who are most interested."

It is hardly necessary for me to comment on the preceding further than to say that the results recorded by Professor Brooks prove in the most conclusive manner that the system of spat-culture proposed by me is feasible, and that we are henceforth in a position to guarantee success in the business of oyster culture if rational methods are pursued.

II. Under the title of *Successful Oyster Culture*, Mr. Fred Mather, in the issue of Forest and Stream for October 1, 1885, writes as follows:

"This summer, by direction of Mr. E. G. Blackford, member of the Board of the Commissioners of Fisheries of New York, and in special charge of the oyster investigation, I began some experiments in the artificial propagation of oysters at the hatchery under my charge at Cold Spring Harbor, L. I. The trial was made under two different conditions, and was successful in each.

"One experiment was made in a wooden tank, 12 feet long, 6 feet wide, and 3 feet deep. This was made of 2-inch pine plank, coated with coal-tar, and supplied with sea-water through three half-inch rubber tubes from a reservoir upon the hill, where it is pumped by a hot-air engine. The bottom of the tank was covered with shells and gravel, and shells were suspended on strings across the tank. On the latter there was no 'set,' but on the shells and gravel on the bottom many were caught. The temperature in the tank ranged, from July 8 to August 31, from 69° to 73° Fahr., standing most of the time about 71°, the density of the water being from 1.017 to 1.020, and standing steadily at the latter figure from July 18 to the close of the season named. At that time, September 1, it was necessary to remove the pipes, clean and tar them for the coming work with cod eggs, and the young oysters were removed from the great pond mentioned below. They were then one-fourth of an inch in diameter.

"The other trial was made in our large salt-water pond, which has a large flood-gate to hold the water at low tide, and from which we pump. This pond is some 280 feet long, 125 feet wide, and about 4 feet deep. Ten bushels of scallop (*Pecten*) shells were spread on the bottom and hung on strings. The swimming spat was put in at the flood-gate while the tide was flowing in, and thus scattered over the pond. On September 19 the pond was drawn down and a splendid 'set' was visible, both on the bottom shells and also on those suspended. On the latter there was a set as high as three feet from the bottom, but the lower ones showed more specimens. The following is from the journal kept by my foreman, Mr. F. A. Walters:

"'*July* 1.—Received first lot of oysters; opened 1 bushel; found 17 ripe females and 1 ripe male; took spawn from these. After 9 hours, as there was no sign of life, considered not good.

"'*July* 4.—From one-half bushel, 9 females and 3 males; milt not active; no sign of life after 10 hours.

"'*July* 5.—From one-half bushel, 11 females, 1 male. Three hours after taking spawn young were swimming; put in tank.

"'*July* 9.—Put in tank 3 pans of spawn.

"'*July* 10.—From 200 oysters, 175 were ripe females, 18 not spawning, and 7 partly ripe males; had to lose all.

"'*July* 11.—From 80 oysters, 60 ripe females, 4 unripe males, and 16 not spawning.

"'*July* 14.—Cleaned tank.

"'*July* 16.—Ground gate of salt pond had to be taken out, owing to a leak. Poor tides followed; pond did not fill for five days; could not pump, and consequently no circulation in tank for that time.

"'*July* 20.—Opened 70 oysters; found 20 ripe males, 30 females, and 20 not spawning. Took 2 pans of spawn at 10.20 a. m.; swimming at 2 p. m.; put in salt pond.

"'*July* 22.—Put spawn from 200 in salt pond.

"'*July* 26.—Cleaned tank; could find no set.

"'*July* 28.—Put in pond 4 pans of spawn in good order.

"'*July* 31.—Put in tank 4 pans of spawn, the best lot taken.

"'*August* 11.—Cleaned tank, and put in spawn from 1 bushel of oysters.

"'*August* 20.—Discovered set in tank.

"'*September* 8.—Cleaned tank; found a number of shells and about a peck of gravel with sets on, but all dead. There were no sets on the hanging shells. The reason for this, I think, is owing to lack of current, which should be quite strong; there is more danger of getting too little than too much. Lowered salt pond.

"'*September* 19.—Found a good set; the hanging shells had sets 3 feet from the bottom, but the shells on the bottom did the best.'"

I need not comment upon the preceding paper by Mr. Mather further than to point out that, taken together with the results reported in the preceding paper by Brooks, the first principle of the theory of spat-culture proposed by me is experimentally demonstrated. That principle as first published by the writer in a preliminary account of his new system of spat-culture in Forest and Stream, October 22, 1885, p. 249, is as follows:

"Oyster embryos, under ordinary conditions in open water, diffuse and affix themselves throughout the three dimensions of such a body of sea-water. This is a well-known and readily verifiable fact."

III. I also stated in the paper cited that "The spat of the oyster will grow and thrive with comparatively little light." In further proof of this statement I will take the liberty of relating a very remarkable observation made by Mr. E. G. Blackford, of New York. During the past season he found that the pipe through which the salt water was pumped from the sound to the reservoir on the hill at Cold Spring Harbor, L. I., was stopped up. Upon investigation it was discovered that the occlusion of the pipe was due to young oysters which had affixed themselves to the inside of the pipe, where they had grown until they had closed it up. In the narrow space inside the pipe, where only a very small amount of light could possibly have had access, it hardly seems conceivable that oysters could have thriven; yet, under the very unfavorable conditions above described, the fixation and growth of young oysters actually occurred. This observation has an important practical bearing on the use of cultch in solid masses, as proposed in the body of the foregoing paper.

IV. Very encouraging success has been reported for the season of 1885 from Saint Jerome's Creek. This season, at my suggestion, the suspension of shells and brood oysters a little distance above the bottom was tried there, galvanized-iron wire netting being used, which was suspended upon stringers supported a few inches above the bottom, upon short piles or stakes. On this the shells were spread. This was intended to overcome the difficulties encountered in the utilization of an oozy or muddy bottom, and enable the operators to shake the netting from the surface or from a boat with a boat-hook, in order to shake off any sediment which might gather on the shells used as collectors. Mr. Ravenel, the superintendent, has reported that "sets" have been obtained on all the different kinds of collectors used this season. He also reports that since a freer circulation has been established through the ponds much better success has been had in obtaining a good set of spat.

V. At Wood's Holl a very interesting observation was made this season, demonstrating the ability of the oyster to affix itself to a foreign body the second time, or long after the animal has passed the ordinary spat or first fixed stage of the first year. While the writer was engaged in artificially fertilizing eggs, the small oysters and shells left over were thrown back into the ponds, in which a large series of wooden collectors made of lath was placed near the bottom, resting upon stringers, and weighted down with bricks. One of the small oysters which had been thrown into the pond as described fell upon one of the bricks edgewise. As this oyster grew very rapidly afterwards, and was in a favorable position for fixation, as the margin of the lower or left valve was extended, it for the second time glued itself firmly to the surface of the brick. This is the first instance of the kind which has fallen under my observation. If similar observations have been made by others I am not aware of any published accounts of them. It is therefore deemed very important that this observation should be recorded, inasmuch as it has recently been questioned whether the oyster fixes itself by the left valve at all.

VI. In a late number of Nature, October 22, 1885, p. 597, Mr. J. T. Cunningham, under the caption of "The resting position of oysters," makes the extraordinary announcement that Woodward, Jeffrey, and Huxley were wrong in asserting that the oyster rests on and affixes itself by the left valve. I am now in a position to state with positive certainty that it is invariably the left valve of the fry of the oyster which becomes affixed to a foreign object. I have examined thousands of very young adherent spat, ranging in size from one-ninetieth of an inch to 2 inches in diameter, and have never found an exception to this rule. Besides the positive statements to the same effect made by Huxley and others, I would refer the reader to a brief paper by myself, entitled "On the mode of fixation of the fry of the oyster" (Bull. U. S. Fish Commission, Vol. II, 1882, pp. 383–387); but I must caution the reader that Figs. 3 to 8 were reversed through an unfortunate oversight, as the apices of the umbones of all the larval shells figured on page 387 should be directed to the left instead of to the right side. Otherwise these figures are accurate. This blunder of the artist is pointed out in the explanation to Plate LXXV, where the figures from the above-cited notice are reproduced in my paper entitled "A sketch of the life-history of the oyster," which forms Appendix II to "A review of the fossil ostreidæ of North America,"* by Charles A. White, M. D., and Prof. Angelo Heilprin. In another paper of mine, "The metamorphosis and post-larval stages of the oyster" (Report U. S. Fish Commissioner, Part X, 1882, p. 784), Fig. 2 shows the larval shell L of the young spat in nor-

*Published as part of the Fourth Annual Report of the Director of the U. S. Geological Survey for 1882–'83, 4to, pp. 275–430, and including Plates XXXIV–LXXXII. Washington, 1884.

mal position with the umbo directed to the left. This figure may be advantageously compared, in respect to the points raised here, with the figure of the external anatomy of the adult on Plate LXXIII in my "Sketch of the life-history of the oyster," already cited. Such a comparison will at once demonstrate that the curvature of the umbones of both the larval shell and of the adult is toward the left. This I find to be uniformly the case with the adults, and in the specimen which had affixed itself to the brick for the second time I also find that the rule holds.

Mr. Cunningham's inference that the left valve, usually regarded as the lower one, is really the upper, because he finds worm-tubes and hydroids most abundant on the convex or left valve, is founded upon an imperfect acquaintance with the habits of the oyster; for if living oysters are thrown into the water, they will invariably fall upon the bottom with the left valve downward. If dead oyster-shells (loose valves) be similarly thrown into the water, they will invariably fall with the hollow side up and the convex one down. And, furthermore, both living and dead oysters remain in just the position in which they fall. Dead shells sown as cultch or collectors fall in such a position and most of the spat is caught on the exposed parts of the under surface only of such shells, whereas little is found to grow on the upper surface. The reason for this is, that the sediment which is deposited on the upper surfaces asphyxiates the very young oyster-spat and other larvæ which affix themselves before they can become established and strong enough to resist its effects. The affixed organisms on the exposed, inclined under surfaces of the shells are, on the other hand, protected from the accumulation of sediment.

It is also well known that the right valve of the oyster is always the most deeply pigmented, while the lower or left one is paler. This is always the case when oysters lie almost flat on the bottom. When crowded together on the natural banks on a vertical position there is less difference between the colors of the valves. This difference is obviously due to some influence exerted by the position of the aspects of the body of the animal in respect to the light, the same as in land and aquatic animals generally. I would conclude, for this last reason alone, that the right valve of the oyster is normally always uppermost, were it not for the fact that I have observed all of the stages of transition from the spat to the adult condition in confirmation of such a conclusion. It is true that many young oysters have the right valve looking down when allowed to grow upon cultch or shells which have been sown upon the bottom to favor the collection of the spat; but that circumstance by no means invalidates, as supposed rather hastily by Mr. Cunningham, the observations and conclusions of such cautious and careful investigators as Brooks, Woodward, Jeffrey, Huxley, Horst, and others.

VII. The annual set of spat on the natural banks is remarkably large. In fact, upon a natural bank the number annually removed is very great; yet, if not deprived too entirely of its original stock, it will again be thickly covered with a natural growth in the course of twelve to twenty months. The conditions on the natural banks for spatting are those of the very crowded collectors contemplated in the plan proposed in the preceding pages. Often as many as thirty to forty oysters will be found crowded upon a single square foot of surface. Upon almost every one of these, young spat will be found adherent towards autumn, so that it is not surprising that the bank is so soon regenerated, appearing a year afterward as if it had never been disturbed, as it bristles with its multitudes of densely-crowded oysters, all of which have the hinge end down, and the free ends of the valves directed upward. The luxuriance of the young growth which adheres to the valves of the parent oysters is fatal to many of the latter, inasmuch as they are finally smothered and killed in great numbers by the rapidity of the growth of their progeny immediately above them.

VIII. Where brush of a suitable kind is abundant, it is not improbable that a very efficient and inexpensive system of collectors could be arranged in the system of zigzag canals described above. Such brush should be dry or stripped of its leaves, and consist of bushes tall enough to reach up to low-water level, and with stems long enough below the branches to be thrust firmly and securely into the bottom of the canal in a vertical position. The bottom of the canal might in this way be thickly studded with vertical brush collectors instead of the more elaborate system of baskets. Or the latter might be combined with a system of brush collectors. The wire receptacles might, in fact, be used to supply the spawn to the canal by filling a number of them partly with dead shells upon which living spawners were laid, and the receptacles then placed at intervals of a few feet apart in the canal, with a dense system of brush collectors arranged in the latter as proposed.

With this modification of the system jetties might also be used, as suggested in the body of the foregoing paper.

IX. In the use of the wire receptacles in the canal system, it will be found that the shells with their adherent spat cannot be left in the apparatus with advantage over ninety days. By that time many of the young oysters will have grown to the size of 2 inches across. They will, in fact, range from that size down to a fourth of an inch across. Figures of spat of *Ostrea virginica* of known age were first published by me, indicating the above-noted rate of growth in 1881. Lieutenant Winslow's results were similar, as based on experiments with collectors the season before.

If the young oysters are left too long in the wire baskets, disadvantageous adhesions will be formed with adjacent shells, so that the young spat may suffer injury and be broken when the shells are separated or poured out of the receptacles. A new and permanent place should therefore be provided for the young spat immediately after it is removed from the collecting apparatus. To that end, it would be best to at once plant the cultch, with its adherent spat, upon a good bottom, where it may be allowed to remain until fully grown. Two hundred bushels of shells, covered with a good set of spat, is an abundance of seed for one acre, as the spat will gain at least thirty to sixty times its own bulk in the course of the next four years, at the end of which time it becomes marketable.

X. Professor Lankester has recently published* some investigations upon the subject of green oysters, and has singularly enough overlooked some of the most important contributions to the subject previously published by others; in fact, he has been, in the main, anticipated by the writer by at least four years, as may be learned by reference to the papers cited below.†

He also seems to have been unaware of the researches of MM. Puységur and Decaisne, published five years ago, the first-named of whom, contrary to the assertion of Professor Lankester, published colored figures illustrating the pigment of *Navicula ostrearia* in 1880, in a memoir, of which I give the title in full below.‡

The second point which Professor Lankester claims to have first demonstrated, viz, the occurrence of *Navicula ostrearia* in the intestine of green oysters, was also previously determined by M. Puységur, as may be seen by reference to the paper cited above, or to a translation of the same in the report of the United States Commissioner of Fisheries for 1882, p. 800, as well as a notice of it published in Nature, XXII, 1880, pp. 549–50.

The third conclusion arrived at by Professor Lankester in the summary of his results given at the close of his paper is not borne out by an examination of sections of the gills of the oyster and clam prepared from specimens affected with the peculiar viridity so well known to European epicures; and, moreover, it does not seem probable that cells which are clearly epithelial should wander back into the circulation and collect together in large cysts in the mantle and also lodge in the ventricle of the heart to the number of many thousands, as I have often observed in green oysters; nor does it seem possible to explain the fact of the whole animal becoming green, with the exception of the adductor muscles, as sometimes occurs on Professor Lankester's hypothesis. There is

* On Green Oysters. By E. Ray Lankester, M. A., LL. D., F. R. S. Quarterly Jour. Mic. Science, Nov., 1885, new series, No. CI, pp. 71–94, pl. VII.

† 1. Notes on the breeding, food, and green color of the oyster. Bull. U. S. Fish Commission, I, 1881, pp. 403–419. (This paper also appeared previously in Forest and Stream.)

2. Supplementary note on the coloration of the blood corpuscles of the oyster. Report of the U. S. Commissioner of Fish and Fisheries for 1882, pp. 801–805.

3. On the green color of the oyster. Am. Naturalist, 1883, pp. 87–88.

4. On the green coloration of the gills and palps of the clam (*Mya arenaria*). Bull. U. S. Fish Commission, V, 1885, pp. 181–185.

‡ Notice sur la cause du verdissement des huîtres. Par M. Puységur, sous-commissaire de la marine, Chevalier de la Légion d'Honneur. (Extracted from Rev. Maritime et Coloniale.) Pp. 11, 1 pl. Paris, Berger-Levrault et Cie., 1880.

no objection to naming the coloring principle absorbed by the oyster *marennin;* and, so far as the writer can discover, this is Professor Lankester's principal contribution to the subject, aside from the claim made for the existence of "secretion cells" in the epithelium of the gills and palps. The existence of cells with the function ascribed to them in his paper is, however, rendered even more doubtful by the fact that sometimes a uniform deep, bluish-green tint becomes apparent not only in the epithelium of the gills, but also in the mantle, throughout which the color may be nearly uniform or irregularly distributed in patches, which shade off imperceptibly into areas not affected.

The fact that the green cells found by me in the ventricle are blood-cells admits of no doubt, as I was careful to compare them with the colorless blood-cells of uncolored individuals. That they are quite free is also unquestionable, as they would immediately separate when the cysts or the heart in which they were contained was opened. The view which I have published in my fourth paper on the clam has therefore not been in the least weakened by what Professor Lankester has published; and, while it anticipates him by several months, it likewise, I think, gives a far more probable explanation of the phenomenon.

I might also add that Professor Lankester's spectroscopic investigations brought him to about the same results as were reached by me with a microspectroscope in 1881.

Finally, I must not forget to mention the crucial tests made by MM. Puységur and Decaisne, as they showed that the coloration could be imparted to oysters at will by simply feeding them with *Navicula ostrearia.* They also proved that when oysters colored in that way were deprived of the kind of food whence the color was derived, in a short time they again became white-fleshed.

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[NOTE.—The references are to page-figures in brackets.]