A METHOD OF LOBSTER CULTURE

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Paper presented before the Fourth International Fishery Congress held at Washington, U. S. A., September 22 to 26, 1908, and awarded the prize of one hundred dollars in gold offered by Hermon C. Bumpus for an original and practical method of lobster culture

CONTENTS.

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THE PROBLEM.

Artifical breeding ought not to be content to do at its best only what nature does unaided. It obtains its real justification only when it is in a position to surpass nature in her achievements. Only thus can it accomplish the task set it—to fill up the gaps caused by years of excessive fishing. (Professor Ehrenbaum, in Mitteilungen des Deutschen Seefischereivereins, Bd. 23, Juni 1907.—Translated.)

In the case of the lobster, nature has made adequate provision for the protection of the eggs up to the very time they are hatched. As is well known, the eggs laid in July or later in the summer or in the early fall are carried attached to the swimmerets under the abdomen of the female lobster, and there are protected until the following June or July, when they hatch out (fig. 9, pl. XI). The young lobsters, also, when they have successfully passed through three moults and have attained the so-called "bottom stages" are equipped with structures and instincts which fit them exceedingly well for holding their own in the struggle for existence; but there intervenes between the hatching and the attainment of the first bottom stage a brief period of two or three weeks in which the young lobsters, having lost utterly the protection of the mother animals, and not yet having acquired either the structure or the instinct which would give them a reasonable degree of individual security, are exposed and helpless to an extraordinary degree.

Those who have studied the question of lobster culture agree that this short interval may properly be called the "critical period" in the lobster's life—the one in which occurs by far the greatest mortality. That the species has maintained itself without diminution (until the recent inroads by man) in spite of this unprotected period may be explained by the enormous productivity of the individuals. A lobster of ordinary size—say 12 inches—produces at one time, according to Herrick, an average of about 20,000 eggs, which are so well protected that practically all of them hatch. This excessive productivity, however, though a potent means of protection to the species, affords no protection to the individuals.

To one confronting the problem of lobster culture these cardinal facts in the natural history of the lobster point out clearly and exactly the line of attack. We can hardly expect to increase the number of eggs per lobster (and fortunately the number is at any rate very large) or to improve on the natural method of protecting and hatching the eggs, for up to the time when the eggs are actually hatched there seems to be little loss in nature. It is during that period directly after hatching, when in nature the larvæ are neither protected from without nor equipped for self-protection, that the great opportunity offers to "surpass the achievements of nature" by protecting these individuals. Not only is this period the weak spot which artificial culture may be expected to strengthen, but the superabundance of larvæ normally produced for sacrifice is advantageous because it furnishes readily the material for cultivation. Still another condition particularly favors the cultivation of lobsters: It is that the critical period between the perfectly protected eggs and the well-equipped bottom-living lobsterlings is so short (only two or three weeks). Altogether, then, there would seem to be no doubt that the greatest practical results of lobster culture can be obtained by concentrating efforts upon protecting the fry through the critical larval period. This has been quite generally and independently recognized as a fact by those who have studied the lobster problem, and it has been an incentive to the many attempts made by experimenters on both sides of the Atlantic to rear lobsters through the larval stages. It has been, likewise, the incentive to a continuous series of experiments and operations extending over exactly ten years, which have resulted in the method of lobster culture presented in this paper.

CHARACTERS AND HABITS OF LARVAL LOBSTERS.

It is a necessary preliminary to an intelligible account of the method itself to sketch briefly the habits of larval lobsters and to indicate some of the peculiar difficulties which the method has to overcome.

Hatching.—The hatching of the ripe eggs of an individual female lobster is a gradual process requiring at least several days and varying with the temperature of the water and perhaps with the lateness of the season. In the latter part of June, when nearly ripe lobsters are brought into the warm water of a shallow estuary, the hatching is accelerated. The fact of the gradual breaking loose of the eggs is undoubtedly of importance in the economy of the lobster under natural conditions, for it prevents the possibility of the swarming of the young fry and the attendant dangers of speedy recognition and capture.

When the larval lobsters first break out of the egg membrane they are closely coiled in the form of an oval spheroid with the terminal segments of the abdomen bent over the rostrum. In a few moments they straighten out and expand and then immediately take up the pelagic life and instincts which they retain until they reach the so-called "fourth stage," after shedding their skins three times.

Mode of swimming.—The young lobsters swim by means of vibratory movements of their exopodite appendages, which stand out like blades from the thoracic legs, and the swimming is augmented by irregular jerky strokes of the very muscular "tail" or abdomen, which, in all the larval stages, is bent at a considerable angle to the cephalothorax. The swimming must be characterized as slow and weak when we have in mind for comparison that of most young fishes. At any time during the three larval stages the fry can easily be picked out by means of a small scoop, or even with the hand.

In general, too, the swimming seems to be aimless in direction, so that the fry are easily carried along by the slightest current. This statement, however, though generally true, requires qualification, for under the influence of special stimuli the movements often become directive. The larvæ respond to varying directions and intensities of light and, in experimental tests, to the direction of electrical currents. They avoid, in many cases, light-colored objects if near, and they are attracted by food to a rather slight degree. They will go only very short distances, however, after particles of food or living prey. During all the larval stages they exhibit practically no instinct of fear and, while they avoid light surfaces, they do not try to escape capture. The heliotropic and photopathic reactions and what may be described as the general aimlessness of movement are things to be reckoned with in developing a practical method of lobster culture.

Food.—The natural food of the lobster must, of course, consist of pelagic organisms. In an examination by Dr. L. W. Williams of the stomach contents of larvæ in all three stages taken from the rearing bags at our station,[a] a large percentage were shown to have fed upon copepods and diatoms. The young lobsters, however, are not distinctly fastidious in this respect, and the nature of the stomach contents of the fry in their natural habitat would doubtless be found to vary according to the variety of available pelagic food.

Moulting and the larval stages.—The instincts and behavior and the general appearance of the three successive larval stages are generally similar in respect to the features just referred to. The stages are, however, structurally well defined and readily recognized, there being for each a number of clearly diagnostic peculiarities. (See text figures p. 224 and 225.) Among the most obvious and easily recognizable are, for the first stage, the small size of the larvæ and the absence of swimmerets on the under side of the abdomen; for the second stage, the somewhat increased size, the presence of several pairs of swimmerets and the absence of "tail fins" or the lateral appendages of the penultimate segment; for the third stage, the presence of both swimmerets and "tail fins." All stages have the exopodite swimming appendages and the corresponding pelagic habit; none has the functional chelæ or "big claws" of the adult lobster.

According to the observations made by Doctor Hadley at our station the average measurements of the three successive larval stages are 8, 9½, and 11

[a] Station of the Rhode Island Commission of Fisheries at Wickford, R. I., on Narragansett Bay.

millimeters, respectively. There is, however, a considerable range of variation in size, particularly in the second and third stages, and there is good evidence that in general the larger specimens are the better fed. For this reason the average size of the lobsters of the various stages in particular rearing experiments forms, perhaps, a basis for judging whether the lobsters are doing well or not.

The length of the combined larval stages varies greatly and is directly and powerfully influenced by the temperature and food. It ranges from nine to

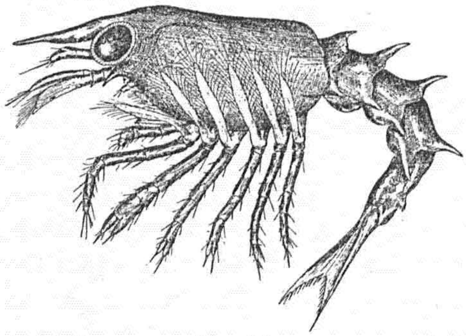

FIG. 1.—First stage.

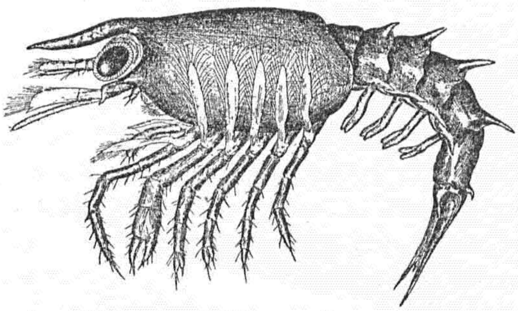

FIG. 2.—Second stage.

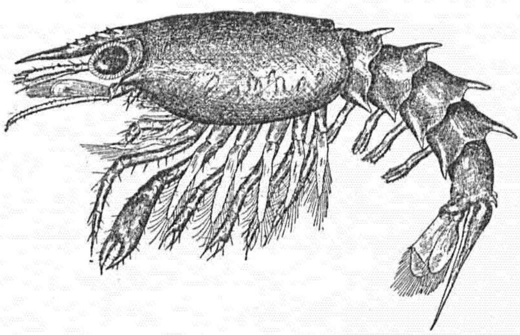

FIG. 3.—Third stage.

LARVAL LOBSTERS, LATERAL VIEW.

more than twenty-five days (twenty-one days is extremely long at Wickford). From the viewpoint of practical culture, the length of the total larval period is of very great importance, though the duration of the first, second, and third stages severally does not seem to be so.

DIFFICULTIES IN REARING.

In artificial culture, of course, the fry must be confined in large numbers, and it is practically impossible to separate them from one another. Therein appears an initial difficulty which all experimenters have had immediately thrust upon them. The fry, under these circumstances, at once exhibit a most

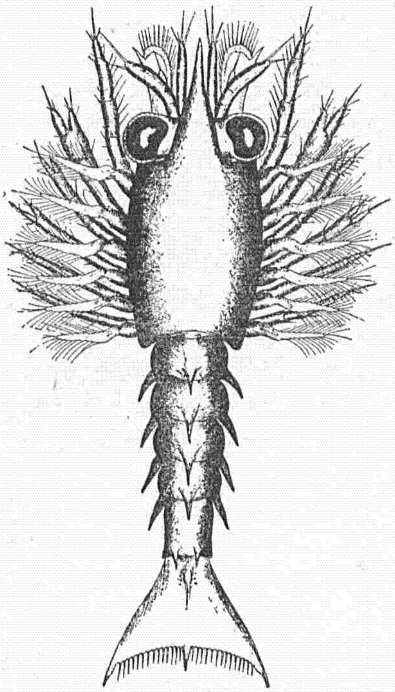

FIG. 4.—First stage.

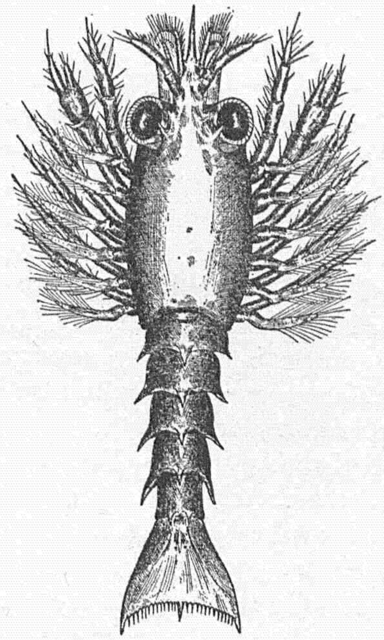

FIG. 5.—Second stage.

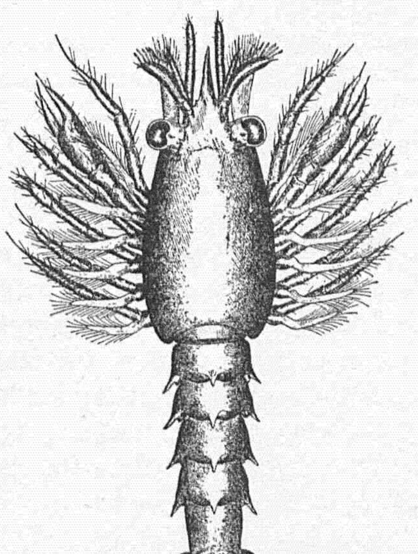

FIG. 6.—Third stage.

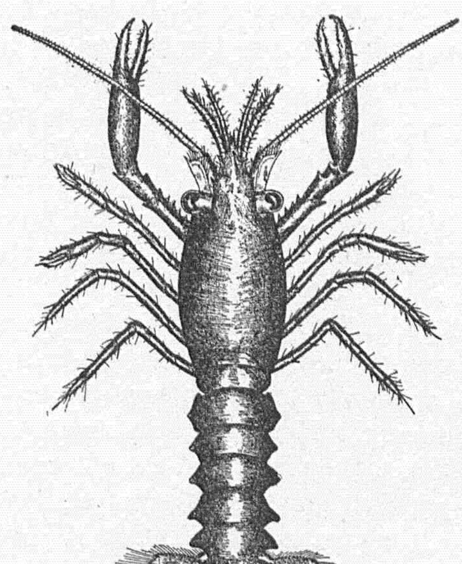

FIG. 7.—Fourth stage.

LARVAL LOBSTERS, DORSAL VIEW.

unnatural and vicious cannibalism which Professor Morgan might well have added to his enumeration of characteristics impossible of development through natural selection and the survival of the fittest, for it can hardly be exercised at all under natural conditions. But whether this evil instinct arises from one or another biological antecedent cause or is a special inspiration in each particular case, its reality is a constant and serious menace to lobster-culture operations. The cannibalistic tendencies are manifested as soon as the fry are hatched and continue throughout the larval period and, for that matter, even far beyond it. Not only do the larger and stronger specimens devour the weaker, but individuals of equal strength attack one another, and, apparently, some initial advantage determines the outcome. During the moulting period the mortality from these sources is naturally aggravated, because it is easy to tear to pieces the soft-skinned, freshly moulted individuals, while they, on their part, are unable to fend off attacks.

Swimming habits.—The comparatively aimless and weak swimming habit which characterizes the larvæ of the first three stages would seem, even in nature, to afford no protection, but for cultural operations, where large numbers of larvæ are given the restricted liberty of a small arm of the sea or are more closely confined in cars of any sort, it contributes to one of the most exasperating difficulties. For example, it happened that when the fry in one of the early experiments of this series were placed in a small cove or inlet from the sea, especially prepared and apparently well adapted to their requirements, they were carried out by the first ebbing tide, and when, subsequently, a screen was stretched across the gateway they were carried against it and left stranded high and dry. In the many attempts to confine them in various forms of cars, when the current was allowed to pass through to prevent stagnation, a like result followed—the unresisting fry were always finally borne against the sides or bottom.

Once upon the bottom the larval lobsters are utterly helpless; they lie upon their sides or backs beating the water with their exopodite "fins" and "kicking" with the whole body. They can not crawl; their only salvation is to "kick" themselves loose from entanglement and once more rise in the water. When confined in considerable numbers, even in still water, they inevitably find their way to the bottom as a consequence of their aimless drifting mode of swimming. There they accumulate in corners, pockets, or eddies, and, entangled in débris, they fight and eat one another until, from injury or suffocation, they all perish. For the full appreciation of these difficulties there must be, however, the personal recollection of particular rearing bags in which from day to day the precious living larvæ vanished from sight, and of the quarts of bright pink colored dead specimens mixed with dirt and silt and remnants of unused food that came into view when the bag was raised for inspection. In one of the earlier experiments 5,000 handsome first-stage larvæ, appropriately designated from their condition the "gilt-edged lot," were placed in a new scrim bag 12 feet square and about 4 feet deep and were carefully tended. Out of the number only two individuals came successfully through to the fourth stage.

Light reactions.—As far as the movements of the larval lobsters are not aimless, they seem to be directed mainly by responses to light stimuli, and vary according to the intensity, color, and direction of rays. They also seem to be modified, indirectly, by background. Doctor Hadley in a study made at our station of the behavior of lobsters observed that the character and responses bore a fairly constant relation, not only to the stage, but to the period within the stage. In cultural operations, where cars are used, the photopathic responses of confined lobsters tend to bring them together into close quarters and are often therefore inimical because of the encouragement that this gives to cannibalism. In attempts to retain the fry in pounds or small estuaries, these responses would very likely tend to carry the lobsters to the shore, to be entangled in the vegetation or stranded at the ebb tide.

Parasites.—External parasites, including stalked protozoa, fungi, diatoms, etc., are often a plague to the confined larvæ. They grow upon the shell and so encumber the larvæ that feeding and moving and breathing also are difficult or impossible. Not infrequently, in fact, the larvæ are so completely covered with these foreign growths that they can hardly be recognized. The parasites are got rid of at each moult, but often they so weaken the larvæ that moulting itself is made impossible. The danger from this source is greatest when, by reason of the low temperature of the water, the duration of the periods between moults is increased.

Food.—Not the least of the difficulties connected with rearing lobster fry is the providing of proper and available food. In small experiments the live copepods and other pelagic food natural to the lobsters in these stages can be supplied; but on a large scale this is not an easy matter. Naturally, food that sinks to the bottom can not be reached by fry that normally swim or float.

Requisites of water, etc.—The foregoing facts regarding the characteristics of the fry in general and the peculiarities which they manifest when in confinement have to be taken into consideration in any attempt to rear the lobster through the critical period of its life. To these considerations must also be added the important question of an adequate supply of water, uncontaminated by chemical or bacterial impurities, constantly furnished with the proper amount of oxygen, and sufficiently free from injurious gases arising from the metabolism of animal or bacterial content. Finally, in any method of lobster culture there must be taken into consideration its practicability when applied on a large scale and its feasibility with regard to the cost of operating.

THE METHOD.

ESSENTIAL FEATURES AND POSSIBLE VARIATIONS.

A method by which lobsters can be reared through the larval stage in such proportions and numbers and at such a cost that it may be called a "practical" method has been gradually evolved at the floating laboratory of the Rhode Island Commission of Inland Fisheries at Wickford, R. I. (fig. 1, pl. VII). Essentially, the method consists of confining the larval lobsters in cars, either of porous material or provided with screen "windows," set into the ocean itself, and of maintaining within the cars, by mechanical means, a continuous gentle current of water having a rotary and upward trend. In details the method allows of wide variation. Good results have been obtained in small cars made out of water pails; in cars approximately 1 foot, 3 feet, 6 feet, and 10 feet in horizontal diameter and 1, 3, or 4 feet deep; and in either square or circular cars of cotton or linen scrim, of bobbinet, of canvas, or of wood. Any constant motive power can be used, according to the exigencies of particular cases—steam, hot-air, or gasoline engines; spring, weight, or water motors; or the water can be stirred by hand, with much labor but good results, as in our early experience. Various forms of power transmission may also, of course, be utilized; belt and rope drives over pulleys and sheaves, and steel shafting with mitered gears, worms, etc., have all been successfully utilized.

HOW THE METHOD MEETS THE DIFFICULTIES.

The way in which this very simple method overcomes the many difficulties of confining larval lobsters may be described in general terms as follows: In the first place the rearing cars are placed directly in the sea, and thereby all the disturbing factors so difficult to control in case of aquarium water which has been pumped and forced through closed pipes, stored in tanks, aerated by air pumps, etc., are at once avoided, and at the same time the various known and the subtle unknown requisites of healthy sea water are assured. The continuous upward spiral current of the contained water is the panacea of numerous troubles. By the upward trend of the current the larvæ are kept always afloat, which is their normal condition and the only one to which they are by structure and habit adapted. The strength of the current easily overpowers their own weak efforts at swimming, sweeps them round and round, and effectually prevents their congregating in common response to the stimuli of light.

When the fry are prevented from getting to the bottom and from congregating anywhere, several difficulties vanish. The effects of cannibalism, which constitute perhaps the most serious difficulty of all, are thereby greatly alleviated, for the fry are to a comparatively great extent prevented from reaching one another, and of course the disastrous effects of their becoming stranded on the sides or lying entangled and fouled at the bottom are also obviated.

Another most important function of the current is the holding in suspension of solid particles of food, so that they come within easy reach of the larvæ. Incidentally, also, it increases the supply and availability of pelagic living food, for the latter is drawn into the car through the bottom and kept alive by normal conditions of the water. An adequate supply of available food is perhaps the most efficacious preventive of cannibalism.

The maintenance of normal conditions of water in a car is also accomplished by this method. The temperature and density of course vary little from that of the surrounding water. The water is constantly renewed either through the porous sides or, in the case of wooden cars, through screen windows in the bottom, egress being allowed for by screens in the sides. Since the current is internal and mainly tangential to the sides of the car, the fry are not carried violently against the ex-current screens, as in the case of a tidal current passing in one side and out the other. There is not much need of rapid renewal of water, however, because the water is continuously brought to the surface by the upward trend of the current, where by exposure to the air it is recuperated with oxygen and relieved of waste gases due to the metabolism of contained animals or the decomposition of unused food.

In a word, it may be said that by this method the pelagic lobster fry may be kept in confinement and under observation in inclosures of natural water, protected from their usual predatory enemies, maintained in natural pelagic condition by being prevented from going to the bottom, provided with either living or artificial food held in suspension, and that the tendency to cannibalism, always evinced when the fry are confined, can be considerably mitigated.

APPARATUS.

The particular form of apparatus by means of which this method has been successfully applied to the rearing of lobster fry during the last few years at Wickford is in some respects a special adaptation to the establishment in connection with which it has been evolved, and certain details of construction are vestiges of former experiments too good to be cast aside, but not to be exactly copied in new construction. As it stands to-day, the apparatus consists of a houseboat built like a catamaran of two pontoons, with a "well" or open space between them, originally intended and used, indeed, for holding experimental cars. At both ends the space between the pontoons is decked and on each deck is a small house. The houseboat floats on the water, moored securely in a small cove directly over the channel in a good tideway (fig. 1, pl. VII). It forms the nucleus of a collection of skeleton rafts which nearly surround it and which all together occupy a considerably larger area than the houseboat itself. Four rafts, 19 by 75½ feet, lying two on either side of the houseboat, contain the cars for hatching and rearing lobster larvæ. The rafts of each pair are bolted fast together and buoyed by barrels (fig. 1). The inside rafts on either side of the houseboat are fastened to the latter with eyebolts sliding over vertical rods to allow solely for up-and-down motion. Each of the four rafts contains six rearing cars, 10 by 10 feet square and 4 feet deep, so arranged that they can be held down in place or raised out of the water to be cleaned (fig. 4, pl. VIII). The rearing cars are provided with removable windows covered with 16-mesh bronze woven wire screens to allow for renewal of water and to prevent escape of fry. There are two windows about 2 feet square on the bottom and two long narrow ones in the middle of two opposite sides.

For several years previous to last summer canvas bags about the dimensions of these boxes and provided also with screen windows were used almost exclusively. They equaled or perhaps surpassed the boxes in point of efficiency when they were in perfect condition, but were less durable and were more difficult to clean.

The apparatus for keeping the water in motion consists of a two-bladed horizontally placed propeller of about 4½ feet radius not unlike those sometimes in use over restaurant tables (fig. 3 and 4, pl. VIII); the latter, in fact, suggested their adoption. The propeller blades are hung inside the car near the bottom and are made to revolve slowly—about nine revolutions per minute. The motive power for the propeller is furnished by a gasoline engine situated in one of the houses and connected with the propeller shaft by a system of steel shafting and mitered gears (fig. 1, 2, 3, pl. VII and VIII). Each propeller can be thrown in and out of gear independently.

HATCHING METHODS.

Handling the egg lobsters.—The method now used in hatching the eggs is simple. The old female lobsters carrying eggs about ready to hatch (fig. 9, pl. XI) are put directly into boxes and the paddles are set in motion. As the old lobsters crawl about on the bottom of the cars, the eggs hatch out one by one and the larvæ, caught immediately by the upward revolving current, are carried up and off the bottom as they are in the ocean. Twenty to 30, or even 50 to 100, lobsters may be put in one car. When the number of old lobsters is large, we have found it well to replace the long propeller by a shorter one hung somewhat farther from the bottom so that the old lobsters will move freely over the bottom with tails extended and not crowd up into the corners. Screens placed over the top of the box, thereby shading them from the strong light, also help to prevent crowding (fig. 7, pl. X). As soon as a sufficient number of fry have hatched out the old lobsters are removed to another car to repeat the operation. The length of time required to hatch out a full complement of fry in one box varies, of course, according to the various conditions; that is, the number of egg lobsters, the condition of the eggs, the temperature of the water, etc.

Precaution as to age of fry.—It is of great practical importance to have a full complement of fry hatch out as quickly as possible—within at least one day—so that all will be about the same age. Otherwise, when the fry moult the older individuals, having passed through the moult and recovered their strength and appetites, are very destructive to the smaller or freshly moulted larvæ. The effects of this discrepancy in the ages among lobsters of one batch are especially injurious when the older individuals reach the fourth stage, for the fourth-stage lobsters are endowed with strength, sagacity, directive power of movement, and voracity of appetite far beyond that of the other stages. When, through a difference in age, a number of lobsters enter the fourth stage considerably in advance of the others, they become veritable "sharks," as they are jocularly called by the attendants. On this account in the first experiments with wooden cars a considerable loss was sustained because certain boxes were reserved as hatching boxes and the fry rather than the "hens" were periodically removed (fig. 5, pl. IX). It being impossible to get them all out at one time, those that remained were often taken out together with a younger lot and later on became "sharks" to this brood.

Circulation current.—For the benefit of the fry there is no doubt an optimum current within the car. The current can be controlled to a surprising degree by manipulating the propellers, although the number of revolutions per minute remains constant. A slight inclination to the blades makes a current very slow, while the maximum inclination creates a current like a mill race. The length of the blades, the amount of taper from base to apex, and the height of the blades in the water cause different effects in the character of the current; for example, the relations of the rotary and the upward components of the current can be thus controlled and varied within wide limits. By these and other variations the fry can be made to scatter evenly at all depths and distances from the center or to occupy various zones or strata. Experience and judgment must decide the question of optimum current at each particular phase. In general, it may be said that a gentle, even current made by a long, well-tapered blade and slight angle of inclination is usually best.

Containers for eggs and fry.—When the rearing was done in canvas bags the old lobsters were confined in crates suspended in the bags, because, if let loose in the bottom, they were apt to tear the canvas. The crates were necessarily less spacious and had the objection of being in the way of the newly hatched fry, which were sometimes swept against them with considerable force by the current. To the other advantages of the wooden car as compared with the canvas bag must be added its capacity to function as a hatching pen. The design and construction of these wooden cars, together with many other recent improvements, should be credited to Mr. E. W. Barnes, the superintendent of the station.

In the beginning of the experiments at Wickford the fry were transported from the Woods Hole hatchery by the Bureau of Fisheries, with whom we were in cooperation. Later experiments showed that the eggs could be stripped off in the usual way and placed in small rearing bags, where they would hatch.

From these the fry were transferred to rearing cars. This method gave place to that of putting the ripe egg lobsters in shallow crates floated near the surface in the big canvas rearing bags, and then the two modifications just described were introduced.

CARE OF THE FRY.

After the fry have been hatched and transferred to the proper rearing car they respond well to careful treatment, and the degree of success of an individual experiment depends to a large degree on the care that is given.

Screens.—Attention to the condition of the screens is worth while, for the intake and outflow of water can thus be regulated and, incidentally, the fine particles of food can be retained in the car for longer or shorter time by this means. The screens which we have used have been made of copper wire, bronze, galvanized iron, galvanized steel, scrim, and painted wire of various meshes and sizes of wire or thread. None is thoroughly satisfactory. They are all apt to clog up or to tear easily. It is to be hoped that the perforated sheet brass or bronze, which has been tried by Professor Gorham to his satisfaction in small experiments, will prove to be a great improvement.

Food.—An appropriate and available food supply sufficient in quantity to fulfill the demands of healthy growth is, of course, a prime requisite in any fish culture, but in the case of the lobster larvæ even this may not be adequate. Not only should the fry have food enough for their healthy growth, but they should never be allowed to go hungry. From hunger to cannibalism is a short step, and although, by means of the current, the fry are kept from congregating, and danger from cannibalism is, therefore, greatly lessened, there still occur chances of individuals coming momentarily in contact with one another, and, if hungry, they make the most of these opportunities. When not hungry, and when the cannibal instinct is not aggravated by the crowding together, they are fairly peaceable.

The question of the best food for the lobster fry is still open. There are many kinds that the fry will eat, and fortunately by means of the stirring apparatus small pieces of almost any kind can be held suspended and therefore made available, but the fry have preferences, and, furthermore, the choice must involve the consideration of cost, the labor of preparation, waste, and the effect upon the water in the cars of the grease or decaying residue.

In some of the earlier experiments several years ago the highly epicurean diet of lobster liver was offered, and the young larvæ, innocent of its antecedents and, as it proved, unaware of its consequences, devoured the finely divided morsels ravenously. This diet did not agree with them and was discontinued partly on this account and partly because for operations on a large scale there were financial objections to its use. Shredded codfish, finely cut or ground fish of various kinds, clams, mussels, raw beef, beef liver, boiled beef, and many other foods have been tried. The fry are extravagantly fond of fresh fish, especially the strongly flavored and oily varieties, but the pieces uneaten foul the car and are therefore objectionable. Clams cut out and finely chopped or ground have been in very general use with us. The expense, however, of digging and opening and the considerable waste in the larger pieces of tough muscle, together with the amount of decayed residue which accumulates in the course of two weeks during which the fry usually remain in one car, are objections to its continued use.

In a careful series of food experiments at our station Doctor Emmel decided, after using clam, liver, beef, and some other foods, that chopped raw beef gave best results, all points considered. However, with a large quantity of fry to feed, it was found to be difficult to prepare cheap raw beef finely enough divided for practical use. Boiled beef coarsely ground (Hamburg steak), boiled, and ground again, and then beaten up in water with an egg beater, was used with gratifying results during the latter part of the present season. It has the advantage that it is easily prepared, even though the cheapest and toughest is chosen, and that when prepared in this way the pieces are small and correspondingly numerous. The particles are readily held in suspension, and when put into the water little by little with a long-handled scoop or shaken through a fine netting (fig. 6, pl. IX) they form a cloud of light-colored and easily visible particles and are distributed so evenly that they are available at every feeding to all the thousands of individuals in the car. Prepared in this manner, the beef leaves scarcely any residue; most of the uneaten finely divided pieces are carried out gradually through the windows. In its use one prime precaution must be taken; it must not be allowed to become stale or previously soaked with water. Care should also be taken to put the raw beef into boiling water and so to coagulate and conserve its albumens.

For the reason alluded to, namely, to keep the larvæ not only well fed but constantly satiated, thereby preventing cannibalism, it is necessary to feed them often, and we adopted the schedule of feeding every two hours through the night and day. Even with the best possible food—and this has yet to be discovered—there is a "knack" in feeding, and it is one of the points in the care of the fry which repays careful attention, for, besides having the advantages just mentioned, adequate food undoubtedly increases the rate of growth and shortens the larval period.

Parasitic growth.—The dangers from diatomaceous, fungous, and similar parasitic growths are especially serious when the time between moults, due to cold water or poor food, is relatively long. For this reason the temperature is a factor to be considered, when possible, in locating a hatchery. At our station the duration of the whole larval period is from nine to (rarely) twenty-one days, most of the larvæ hatching in about twelve to fourteen days. We have found that shading the cars, as Professor Gorham recommended, seems to prevent to a marked degree the growth of diatoms, and also that in the wooden cars recently adopted the annoyance from this source is very slight when the cars are shaded. The insides of all of the boxes were painted, four of them white and the rest green. We could not see that either color had an advantage, judging from the output of fry. Whether the comparative immunity from diatoms of fry in boxes as compared with those in canvas bags was due to the painted surfaces of the wooden sides or to some other factor it is difficult to say. Animal growths, barnacles, molgulas, oysters, mussels, etc., were abundant even on the painted surfaces, and were scraped off each time the cars were raised. Canvas screens on frames (fig. 7, pl. x), set up like the sides of a roof so as to afford shade and to shed rain water, which occasionally comes down in such quantities as decidedly to freshen the upper strata of water, are strongly to be recommended.

RESULTS.

CRITERIA OF EFFICIENCY.

As was stated at the outset, this series of experiments and operations was undertaken in the conviction that the paramount problem of lobster culture was to raise the larvæ to the fourth or lobsterling stage. It has been constantly borne in mind that a method of doing this to be practical must be able to produce large quantities and without too great expense either for the cost of the plant or for operation. Further criteria of efficiency are, first, the proportion of fourth-stage lobsters to first stage, and, second, the number of "fours" to egg lobsters, provided, of course, that the egg lobsters on hand do not overcrowd the capacity of the particular plant. In placing a value upon proportions of "fourth stagers" to newly hatched fry, the number of fry dealt with in a single experiment has been considered; e. g., a proportion of 50 per cent carried through in an experiment with 500 or 1,000 fry can not fairly be compared with the same proportion in an experiment in which 5,000 or 20,000 fry are used. We have allowed ourselves also to mark our progress and the value of the method by comparison, first, with our former results, and, second, with the experiments undertaken elsewhere having the same end in view.

YEARLY PROGRESS AND OUTPUT.

Since this year happens to be the decennial of this particular series of experiments and operations, the presentation of a short summary of yearly results in regard to total output is appropriate.

In 1898 Doctor Bumpus, now the honorable president of this congress, and at that time director of the United States Fish Commission laboratory at Woods Hole and member of the Rhode Island Commission of Inland Fisheries, had the faith and courage to undertake a new series of experiments in rearing the larval lobsters. Judged by the ingenuity put into them, and the experience and encouragement got out of them, these experiments during the first year were successful, though the number of fry reared was small. The total output is summarized in the report of the work in these words:

> Several lobsters were actually raised to the stage when the characters of the adult are assumed—the fourth moult.[a]

The next year, 1899, the results were better because of the use of "a large bag of scrim made after the fashion of a fish pocket and hanging down into the water from a square floating frame." The output is given in the following words:

> By the methods above described, and after many failures, accidents, and reverses, we succeeded in raising several hundred lobsters to the fourth stage.

During the following season, 1900, several lots of newly hatched fry were transported from the United States Fish Commission station at Woods Hole to the new floating laboratory of the Rhode Island Commission of Inland Fisheries at Wickford, R. I. (the two commissions working in cooperation), where further experiments with scrim bags were started parallel to those still being conducted at Woods Hole. At the floating laboratory at Wickford the trials and reverses of the previous year at Woods Hole were again experienced, but the experiments were under the eye of the person in charge, by night as well as by day, because the small houseboat functioned as a residence. The greatest virtue of the loosely hung scrim bags consisted in the undulatory "peristaltic" movements, due to wind and tide, which tended to keep the lobsters off the bottom, but it was observed that during the nights there were periods of dead calm and of slack tide, when the fry sank to the bottom and died. This led to the simple conclusion that if the fry, left to themselves, persisted in sinking to the bottom to die they must be stirred up and prevented from sinking; so after this they were stirred with an oar continually night and day. The total reared to the fourth stage was 3,425. The results showed unequivocally that the proper principle had been discovered, and immediately plans were laid to substitute a mechanical apparatus by which this method could be less laboriously carried into effect. Curiously enough, some large two-bladed fans revolving over a restaurant table for the purpose of driving away flies suggested the type of apparatus suited to the purpose, and this type has been in use ever since.

The next year, 1901, the United States Bureau of Fisheries again cooperated with the Rhode Island commission. Some of the fry were imported from Woods Hole and some were hatched at Wickford. An apparatus for using the two-bladed propeller was designed and installed by Mr. G. H. Sherwood. The results confirmed the correctness of the principle, and the output for the year was 8,974.

During the subsequent years the method has been developed and the apparatus again and again remodeled to incorporate the results of our failures and

[a] Bumpus, Twenty-ninth Annual Report of the Rhode Island Commissioners of Inland Fisheries, 1898, p. 98.

successes and in the effort to obtain results on a scale large enough and with cost small enough to deserve the adjective "practical." The total outputs for the years are:

1898	[a]	1902	27,300	1906	[c]189,384
1899	[b]	1903	13,500	1907	[d]294,896
1900	3,425	1904	50,597	1908	[e]322,672
1901	8,974	1905	103,572		

The rearing of considerably over 300,000 lobsters in the small plant at Wickford recalls the confession of faith written ten years ago, at the conclusion of the first season's work:

> We know perfectly well that many others have failed in doing what we attempt, but until we are thoroughly convinced that the young lobster can not be "brooded" we propose to continue our work.[f]

Manner of determining output.—It was early realized that "estimates" of the number of lobsters in experimental work are practically worthless and therefore all the fourth-stage lobsters which are taken account of at all (many thousands of others have accidentally escaped) have been individually counted. Within the last few years, when the numbers have run up into hundreds of thousands, the operation of counting individuals has consumed much time, but the satisfaction of accuracy in results has been sufficient compensation. A comparatively easy and very accurate method of counting is now in use. The "lobsterlings" are dipped out of the hatching boxes with flat woven-wire strainers which take up from one to twenty at a sweep; these are recorded on an automatic counting register held in the hand. The count at each sitting is then posted (fig. 7 pl. x).

It is of little use to estimate the number of a lot of first-stage fry. More than once the lots so estimated, even by experts, have yielded not more than 10 per cent of the estimated number; sometimes, no doubt, they would run considerably over. For this reason, in order to ascertain the proportion of newly hatched fry to the fourth stage, the individuals must be counted both before and after the experiment. This is a rather tedious process, but it is warranted and necessary when new methods or new devices of construction are tested for their relative efficiency.

Tested by this method both the large canvas bags used until this year and the present boxes have yielded on several tests 40 per cent of fourth-stage lobsters from lots of 20,000 newly hatched fry. In one test of the canvas bags 48.2 per cent were obtained in a 20,000 lot. In testing for relative value of foods in

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[a] "Several."
[b] "Several hundred."
[c] 24,800 to fifth stage.
[d] 4,900 to fifth stage.
[e] 5,481 to fifth stage.
[f] Bumpus, op. cit.

1907, 40.6 per cent and 39 per cent were obtained in two respective tests, while one of the boxes yielded 42 per cent. About 40 per cent may be considered a fair yield for lots of 20,000 under the present system of operation. By using more fry more fourth-stage lobsters can be obtained from a single car, but the percentage probably falls.

There is another very different point of view from which the efficiency of the present method may be judged, namely, the number of fourth-stage lobsters which it will produce per egg lobster under fair conditions. Toward the latter part of the season two years ago, when the supply of eggs from the ordinary source had suddenly been cut off, 56 egg lobsters were received from Noank through the courtesy of the Connecticut Fish and Game Commission. From these there were hatched and reared to the fourth stage 84,896 young lobsters, giving an average of somewhat over 1,500 per egg lobster.

SUMMARY AND INTERPRETATION.

Summarizing the actually obtained results of rearing lobster fry to the fourth stage by the method herein described: Since the present method was first put into operation in its crude form where the water was stirred by an oar the output has each year (with one exception) increased. The extremes are represented by the total of 3,425 in 1900 and of 322,672 in 1908. The grand total for the eight years is 1,014,320, more than half of which were produced in the last two years. With lots of 20,000 newly hatched fry from 40 to 48 per cent (counted) have been carried through to the fourth stage frequently, and 40 per cent may be said to be a fair average to expect under good conditions. From 56 egg lobsters nearly 85,000 fourth-stage lobsters were obtained, showing an average of about 1,500 per individual.

In order to interpret these results fairly, there are certain things which deserve consideration. Even when operating on a practical scale, we have been feeling our way over new ground to further improvement of the method. Not a year has passed without decided changes in the method or the apparatus. While this procedure leads to the best final outcome, it does so at a sacrifice of immediate results. Accidents, also, of certain classes—for example, the loss of larvæ through broken screens—must be charged against the present apparatus and not against the method. Delays in construction, difficulty in getting egg lobsters, etc., may be due to misfortune or to mismanagement, but do not affect the permanent value of the method.

Capacity and efficiency of plant.—The plant as it stands to-day must be judged by the results actually attained; but having watched closely its operation I may venture the personal opinion that it has not yet produced to its full capacity and that the 24 cars are capable, under good conditions and with allowances for inevitable mistakes, of hatching and rearing 500,000 lobsters in the six or eight weeks which constitute an average season. This is a conservative estimate based on the following deductions: If all the 24 cars were filled three times, allowing two weeks for passing through the moults, with an average output per car of 10,000 each time (which is considerably below frequent actual production), the total output would be 720,000. With a constant supply of fry sufficient to fill the plant to its full capacity throughout the season, this estimate could probably be raised.

As has been stated before, many features of the present installation are to be considered as vestigial structures and others as designed for one function and adapted to another in the course of the evolution of the plant. A new plant, therefore, built to operate the same rearing cars would be different in many details. The cost of a plant capable of duplicating the work of the one at Wickford has been calculated by Mr. E. W. Barnes, superintendent of the Wickford plant, at approximately $2,000, specified as follows:

COST OF A REARING PLANT CONSISTING OF 24 REARING BOXES CAPABLE OF TURNING OUT OVER 500,000 LOBSTERLINGS IN A SEASON.

2½ horsepower engine	$200	24 boxes	$350
Houseboat	300	Miscellaneous supplies	200
Four rafts	350		
Gearing	400	Total	1,800

The above items have been figured economically but quite liberally, and in localities where materials can be readily secured the cost might be considerably lessened. The actual cost of rearing lobsters to the fourth stage is a little less than $3 per 1,000. This includes labor, food, gasoline, and in fact all necessary running expenses, but does not include the cost of egg lobsters.

This amount would, of course, vary with the time and place where the plant was constructed and also with the kind of materials used.

Self-protective ability of fourth-stage lobsters.—An acquaintance with thousands of fourth-stage lobsters from personal observation and through the special scientific studies of members of our staff increases even our former estimate of their superiority over the larval lobsters. Immediately after arriving at this stage they are able to crawl over the bottom, to burrow and hide, to fight, and to forage in most striking contrast to the larval lobsters in any stage of development. In the first few days of the fourth stage the lobsterlings are good swimmers—this is their "redeeming vice"—but the swimming is strong and bears no comparison to the aimless drifting movement characteristic of larval stages. The lobsterlings dart hither and thither in pursuit of food, and for the first time they show a decided fear and strive to avoid capture. When left in the rearing cars, which have a strong internal current of water, thousands of these lobsters are often seen all swimming mightily in one direction against the strong current for hours at a time; but these same lobsters when taken out of the car and put into another one provided with sand and gravel will often take immediately to the bottom and behave as if they had always lived in this habitat.

It is an interesting and important fact that the tendency to swim decreases rapidly during their sojourn in the fourth stage and also that they can be encouraged to live on the bottom by being brought into contact with it. These facts have suggested two modifications in the usual procedure in liberating lobsters—first, that of holding the lobsterlings in special rearing cars for a few days after they reach this stage, keeping up the current in order to keep the lobsters separated and to keep their food in suspension, and, second, that of liberating them in such a manner that they will immediately touch the bottom, in which case they are not so apt to make swimming excursions through the water. An ingenious device for the latter purpose has been invented by Mr. Barnes. The young lobsters are sunk in barrels which have the numerous holes for their exit so covered up that while the lobster can get out predacious fishes can not get in.

It is comparatively easy to care for fourth-stage lobsters. Space and plenty of food are about the only requisites. Like the fry, they are cannibals in proportion as they are hungry and crowded together; but unlike the fry, they control their own movements and go where they please, whether swimming, or crawling, or burrowing, and they have, moreover, a strong instinct of self-preservation.

Fifth-stage lobsters.—There is much to be said in favor of rearing lobsters to the fifth stage before liberating them, and this is not difficult to do, but requires space. In some experiments conducted without great care 80 per cent were carried from the fourth to the fifth stage in large lots of several thousand. In addition to the advantage in the matter of size, strength, and bottom-loving instinct, which favors the fifth-stage lobsters, an additional advantage lies in the fact that the duration of the fourth stage can be shortened by abundant feeding. Doctor Emmel showed in a most convincing manner that by feeding alone, all other conditions being identical, the duration of this moult can be varied from an average of eleven to an average of twenty-four days.

Liberation of young lobsters.—Every visitor at the rearing plant asks the embarrassing question, "What proportion of the liberated lobsters live to grow up?" Only once was a definite and satisfactory answer given to this question and that by a new recruit on his first day's duty.

In 1901 when the experiments began to indicate that a large number of lobsterlings could most likely be liberated from our establishment, investigations were started to find out whether the physical conditions of the waters of Narragansett Bay were such that the young lobsters could live here throughout the year. Of this there is now no doubt, for the specimens reared from the egg have year after year been kept over winter in cars sunk or floated in the harbor at Wickford. Several were kept for three successive years and finally were lost through accident.

EVIDENCE OF INCREASE IN LOBSTER SUPPLY.

The young lobsters have been liberated mainly in the upper half of Narragansett Bay, because for many years previous to our operations small lobsters have been conspicuously absent from these precincts, according to the statements of fishermen. Within the last three or four years a great many reports have come in of small lobsters from an inch to 4 or 5 inches in length being caught in the lobster pots and escaping through the slats when the pots were drawn up; also of small lobsters up to 8 inches in length dug out of the mud in the early spring by the clam diggers. These reports have been numerous and are increasing and apply to those particular districts in the upper part of the bay in which our lobsters have been liberated. They have occasioned remarks of surprise by the fishermen, because this region has been so long barren of small lobsters. Whether this can be taken as good evidence of the effect of liberating in these waters about half a million of young lobsters reared to the bottom stage (the number up to two years ago) is at present of course entirely a matter of opinion.

ECONOMIC EFFICIENCY OF THE METHOD.

At the end of an account of the method of rearing lobsters and of the results actually attained, a brief speculation with regard to the efficiency of the method from the economic standpoint may be permissible.

It is often true in biology that one can draw conclusions as to causes and effects from observation and comparison of normal occurrences. In the breeding of animals we seem to have a case in point. Fishes which produce many thousands of eggs at a time, but whose young are left almost utterly unprotected, often do not maintain so great a numerical abundance as do other species (like the dogfish), which produce only a very few individuals at a time, but give the young a high degree of protection.

While the relative values of the larval and fourth-stage lobsters can not, for a long time at any rate, be determined accurately by direct experiment, it would seem that a comparison of the breeding habits of the lobster and the crayfish would, as Ehrenbaum has pointed out, furnish data for a tentative valuation. Where the lobster produces at one time 20,000 fry (Herrick got an average of 21,351 eggs from 414 observations of 12-inch lobsters), the crayfish produces approximately 100 young (Ehrenbaum), which it protects to a stage comparable with the fourth-stage lobster. Assuming, then, that the 100 young fourth-stage lobsters and the 20,000 newly hatched lobster fry are of equal value for maintaining the species, the ratio of individual values would be 200 : 1. Our method of artificial culture is capable of obtaining 8,000 fourth-stage lobsters from 20,000 fry. It is able, therefore, by taking advantage of the lobster's great productivity, to obtain 80 times as many young of this particular advanced stage as are necessary for the maintenance of the species under natural conditions.

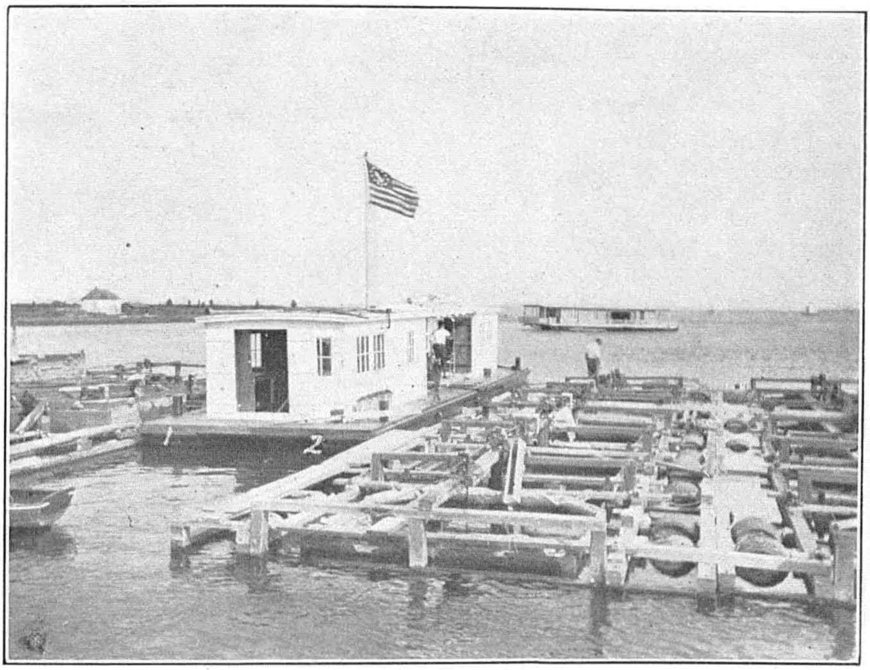

FIG. 1.—General view of house boat with floats attached, looking forward. The ends of the pontoons show at 1 and 2. The general relation of the rearing cars, alleyway, and barrels is seen in the right-hand floats.

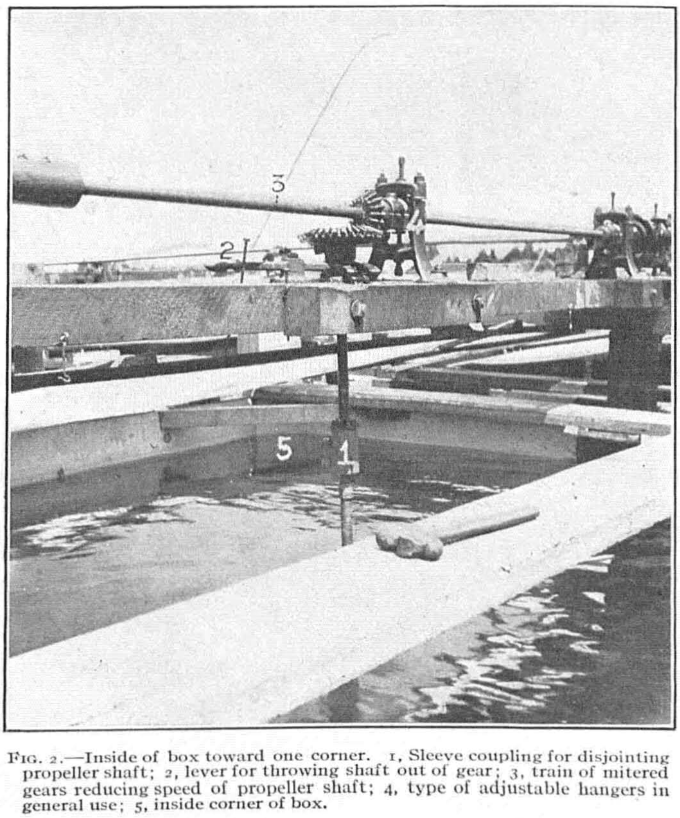

FIG. 2.—Inside of box toward one corner. 1, Sleeve coupling for disjointing propeller shaft; 2, lever for throwing shaft out of gear; 3, train of mitered gears reducing speed of propeller shaft; 4, type of adjustable hangers in general use; 5, inside corner of box.

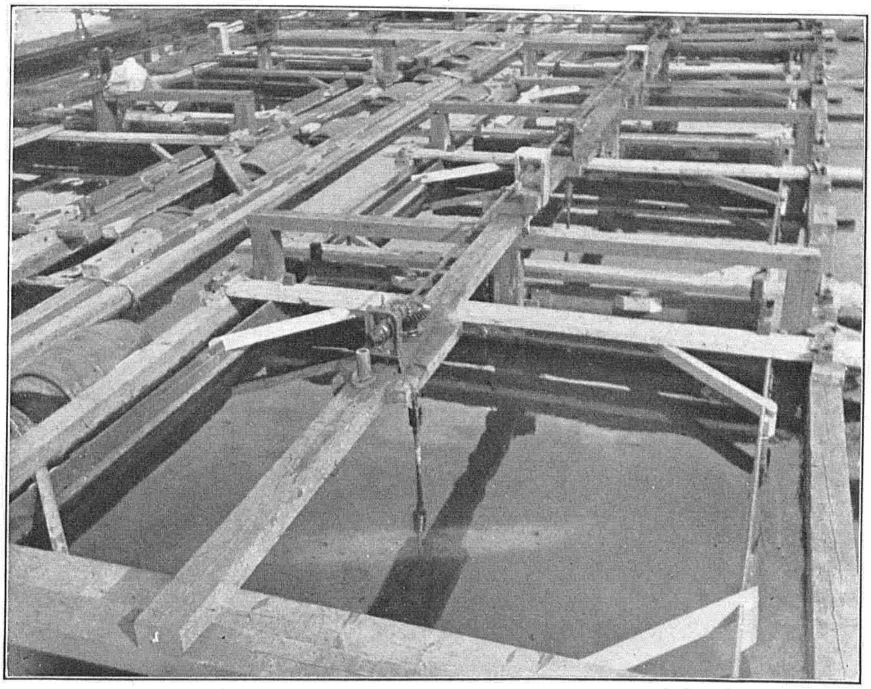

FIG. 3.—Floats from outer corner looking forward and toward house boat. The appearance of the car in the water and the gearing of the propeller shafts are shown in the nearest car.

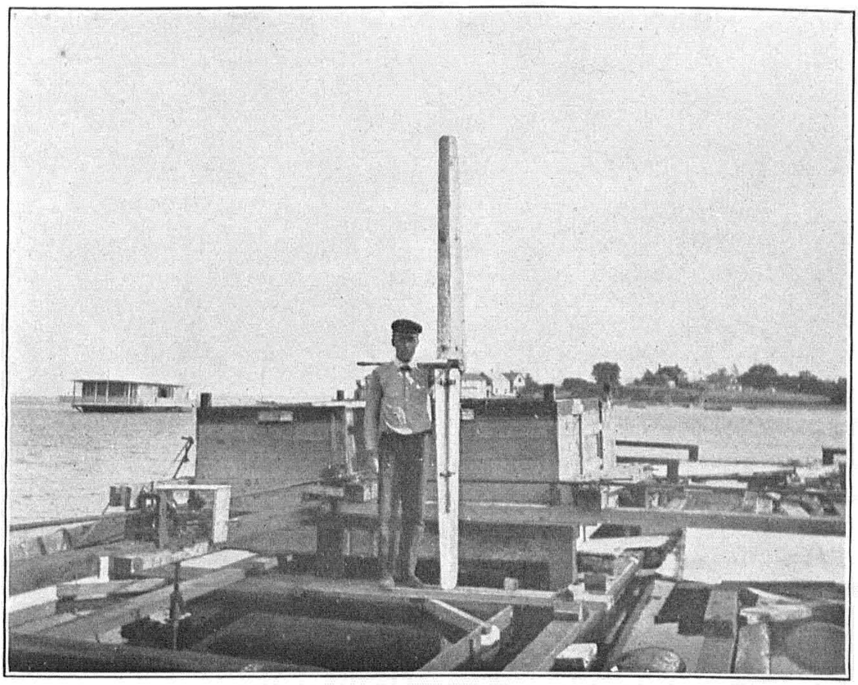

FIG. 4.—One of the outside floats, car raised. The size and shape of the propeller is well shown.

FIG. 5.—If the fry have to be transferred, they are scooped out on a flat net of this style and immediately shaken off into a tub of water, thence taken to the car prepared for them.

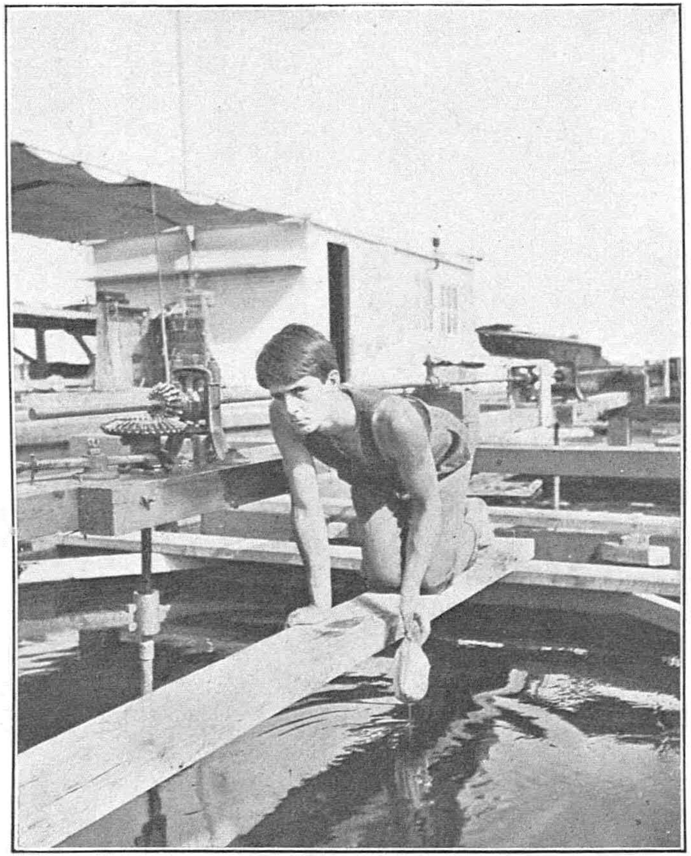

FIG. 6.—Feeding by means of ground food shaken from a piece of netting. This prevents the larger pieces of food from getting into the car and also tends to prevent any sticking together of smaller pieces.

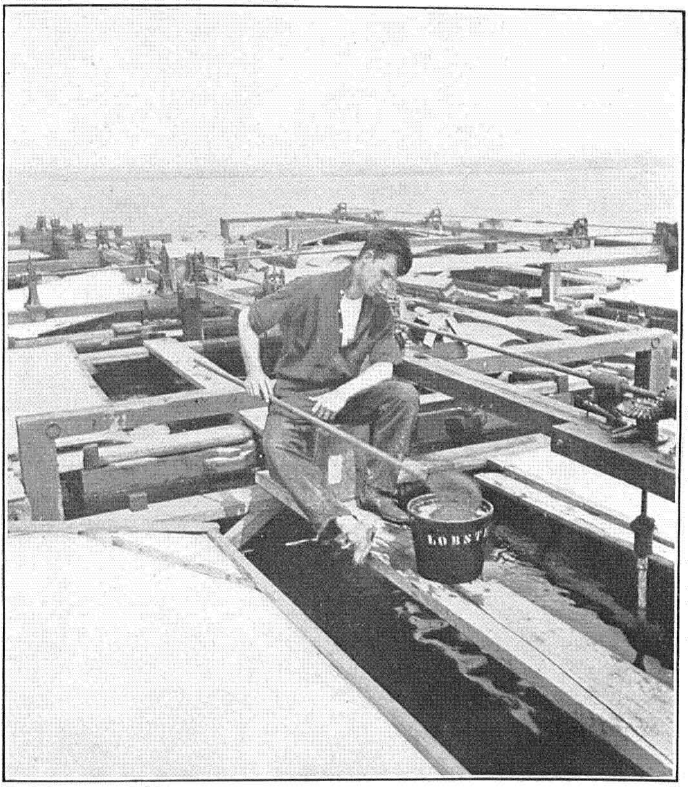

FIG. 7.—Method of counting fourth-stage lobsters. The awning is laid aside. The lobsters are caught up in the woven-wire dipper and shaken off into a bucket of water. In the left hand is held the automatic counter.

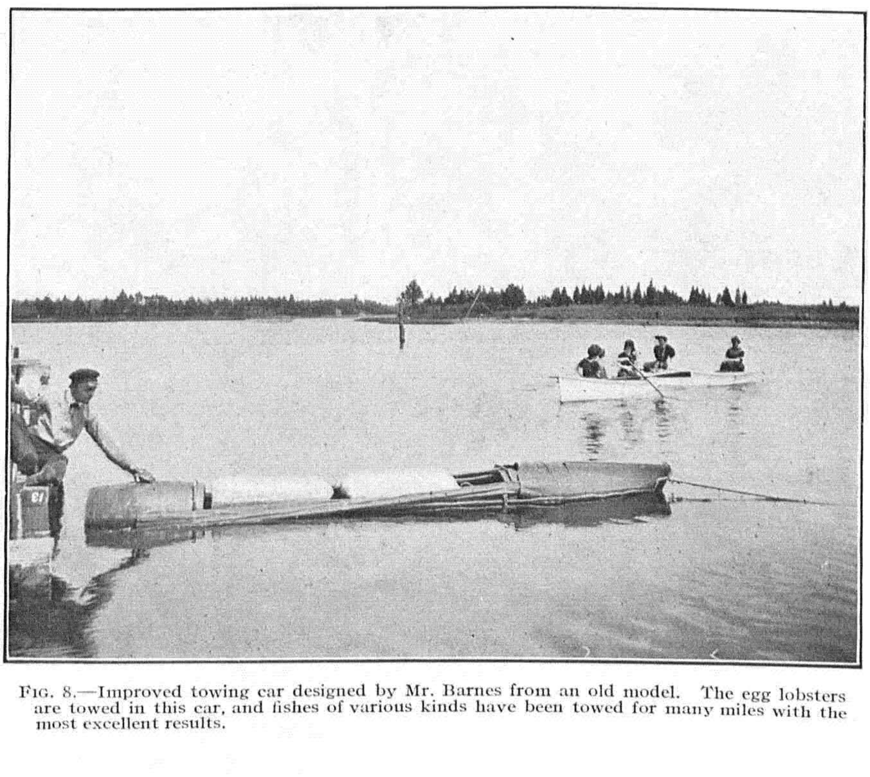

FIG. 8.—Improved towing car designed by Mr. Barnes from an old model. The egg lobsters are towed in this car, and fishes of various kinds have been towed for many miles with the most excellent results.

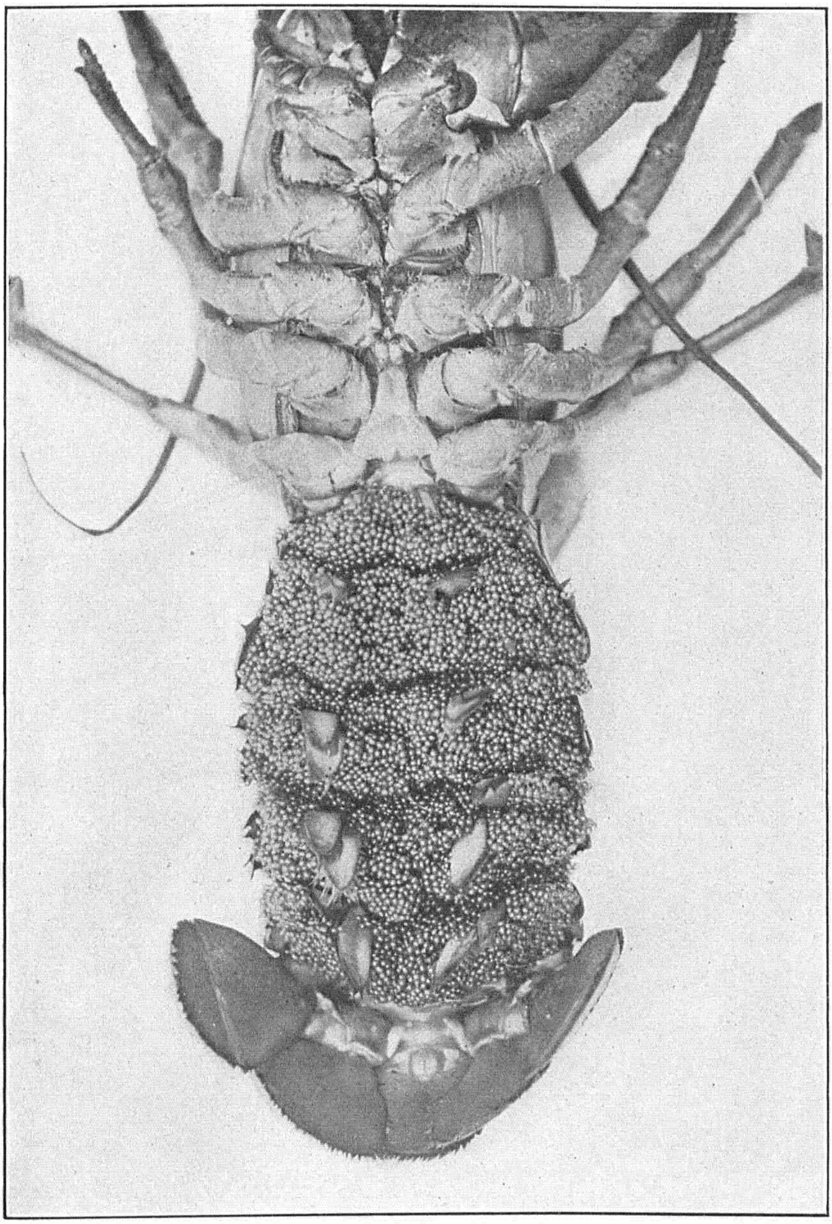

FIG. 9.—Lobster with eggs.