A NEW PRINCIPLE OF AQUICULTURE AND TRANSPORTATION OF LIVE FISHES

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BUREAU OF FISHERIES DOCUMENT NO. 676
Issued April, 1910

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By A. D. Mead, Ph. D.

Member Rhode Island Commission of Inland Fisheries

Paper presented before the Fourth International Fishery Congress, held at Washington, U. S. A., September 22 to 26, 1908, and awarded the prize of two hundred dollars in gold offered by the United States Bureau of Fisheries for a report describing the most useful new and original principle, method, or apparatus to be employed in fish culture or in transporting live fishes

CONTENTS.

FIG. 1.—Floating laboratory and rearing plant from the port side. The forward (left) house serves as a laboratory and the after one as the engine house and tool room. Most of the rearing cars are covered with white awnings.

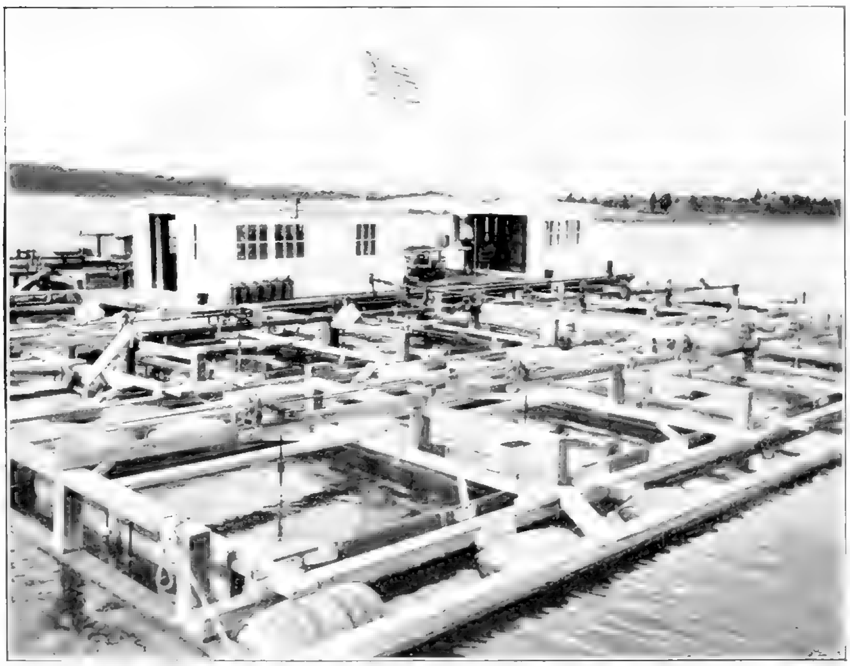

FIG. 2.—General view of the plant from the outer rear corner. In foreground one of the cars shows the propeller shaft and faint indication of propeller blades in the water.

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By A. D. MEAD, Ph. D.,
Member Rhode Island Commission of Inland Fisheries.

ESSENTIAL FEATURES AND DEVELOPMENT OF THE METHOD.

The method and apparatus herein described as a novel and practical method of fish culture have gradually developed through eleven years of continuous experimentation at the marine station of the Rhode Island Commission of Inland Fisheries. It may be said, indeed, that the method and the station have developed together. The aim has been throughout to provide as simply as possible the essential features of the natural environment, biological and physical, for aquatic animals while kept in confinement, and to introduce as little as possible the unnatural features which are frequently considered necessary in artificial culture. Upon this principle there has been sought a feasible method of providing water agreeable to the particular species in regard to the various component salts, well aerated but not over aerated, having the proper temperature, density, and current, and containing appropriate food in available condition; while providing at the same time for the elimination of waste products of animal respiration, and avoiding the dangerous chemical and bacterial impurities almost invariably present where the water is passed through systems of piston pumps, closed conduits, and storage tanks, and is aerated by means of forced air.

The first step in the development of the method was a very direct and simple concession, namely, that of going to the ocean instead of trying to bring the ocean into a house on land. The floating laboratory and hatchery was therefore adopted as a feasible method of circumventing, if not surmounting, many difficulties.

During the first and second seasons of work it was clearly demonstrated that the starfish (*Asterias forbesii*) could be reared in the course of the summer (four months) from the larval stage to over 50 millimeters measured from mouth to tip of arm (nearly twice the length of sexually mature specimens captured in June, the breeding season, and therefore a year old), in cars of appropriate shape floating in the water between the pontoons of the houseboat. In this case living food was supplied at first in the form of small barnacles which had set on boards, and later, as the starfishes grew larger, clams, oysters, and mussels were given them to eat. The conditions in these cars were completely adequate for the healthy life of these slow-moving animals, and were abnormal only in that the young starfishes were protected from their enemies (excepting always their cannibal brethren) and were better fed than they often are under natural conditions. In many cases where they were especially well fed they far outstripped in rapidity of growth individuals found along the shore. They throve splendidly and were perfectly healthy.

This way of raising starfishes may hardly be dignified by the term "method," and yet the better condition of these specimens as compared with those usually seen in an aquarium—even in an aquarium where many fishes live for a long time—is a striking fact. It suggests also that there is often something the matter with aquarium water which, whatever the cause, makes it unsuitable for the rearing of very sensitive animals.

At the floating laboratory, animals with the burrowing habit can also be kept confined and protected and under constant observation by simply putting them into a box of sand suspended in the water. Specimens of the soft-shell clam (*Mya arenaria*) may in this way be very successfully and rapidly reared, and they give every indication of being in a perfectly normal environment. Indeed, in our experiments, when they were kept just under the surface of the water and in the tidal current, they grew more rapidly than in the most favorable shore locality I have ever seen. In one experiment with clams ranging from 5 to 17 millimeters the increase in bulk during five weeks and two days was 1,861 per cent.

In the case of sessile animals like oysters, *Crepidula, Anomia, Molgula, Botryllus*, sea anemones, tubiculous worms, etc., and of those which spin a byssus, like the mussel, young clams, and pectens, it is only necessary to provide the proper surface for them to set on and protection from predatory animals. In case of the hatching of such eggs as those of the flatfish, *Menidia, Fundulus*, and the lobster, with which we have had experience in the course of our operations, it would seem that the term "hatching" could hardly be used in a transitive sense, for, if the eggs are provided simply with water of proper constitution, temperature, and conditions for respiration, the eggs inevitably hatch themselves. These nonpelagic eggs, in fact, belong to the same category as the sessile or slow moving animals and may be treated accordingly. The method of stripping and swirling lobster eggs has been given up with us and instead the ripe-berried hen-lobsters are allowed to crawl about in the rearing cars with the result that the eggs hatch most satisfactorily. Similarly the eggs of the flatfish (*Pseudopleuronectes*) were hatched with almost no loss by placing them on a piece of scrim which formed the bottom of a box about 6 inches deep floated on the top of the water in a protected pool. The eggs of *Menidia* and *Fundulus* are hatched successfully by practically the same treatment.

ADAPTATION TO FISHES AND OTHER PELAGIC FORMS.

REQUIREMENTS.

In the development of the method of fish culture with which our station is identified the installation of a laboratory directly upon the water and the confining and rearing of animals in cars placed in the water marked the first step. For many animals of the types we have mentioned, the slow moving, or creeping, the burrowing, and the sessile animals, this is all that is necessary for rapid and healthy growth. For pelagic animals, however, like the young of most fishes and the larval forms of crustacea and other marine invertebrates, it is not sufficient. The very peculiarities of structure and instinct which adapt these creatures to their pelagic life make it difficult to confine them for a long time even in relatively large inclosures of the water in which they normally live.

One is baffled now by one peculiarity and now by another. The larvæ or fry are often strongly heliotropic, and in going toward or away from the light soon strike the boundary wall of their confine, and when they are numerous, as they must be in practical culture, die from the effects of crowding, if, indeed, they are spared to this fate by their cannibalistic comrades. Often in the blind struggle to go toward the light regardless of the boundary wall, they gradually work their way to the bottom and become entangled in débris or covered with silt.

If, for the sake of good circulation of water, the tidal current is allowed to pass through the car, as in the case of sessile or bottom-living forms, the pelagic fry are apt to be swept against one side, or to collect in eddies, with disastrous results. If, on the other hand, the current through the inclosure is not supplied, the water becomes stagnant and not well aerated, and since the time required to rear most animals to a considerable size is long, the stagnation under these circumstances is almost inevitable.

The minuteness of many larval animals constitutes a fourth difficulty, for perforations or meshes large enough to permit sufficient circulation frequently permit also the escape of the fry, while meshes too small for the fry to go through become clogged with silt and do not allow free circulation.

The fifth difficulty in the rearing of pelagic fry in inclosures of this kind depends upon the fact that normally they capture their prey "on the fly." A dilemma presents itself: If the fry are fed upon smaller animals or plants, these too must be pelagic, involving all the difficulties over again, while, if artificial food is used, there is no provision for keeping it in suspension, in which condition only would it be available.

REQUIREMENTS SATISFIED.

After the first step was taken and the excellent result of rearing bottom-living animals in native water was recognized, it seemed most desirable to follow up the advantage gained in the rearing of other forms by extending and developing the procedure so that it would be applicable to pelagic fry. Fortunately we were able to hit upon a method which solved at once all the main difficulties arising from the peculiarities of pelagic existence of larvæ and other free swimming animals. This method consists essentially of creating and maintaining within an inclosure of "native" water a gentle upward swirling current. It obviates the several difficulties which we have enumerated as peculiar to pelagic fry in the following ways:

It effectually prevents the crowding of the fry to one wall of the car, for the force of the current carries them round and round continuously, nor can they work their way to the bottom, for the current has an upward as well as a rotary direction. Even the cannibalistic propensities, which are so pronounced in the larval stages of lobsters and some other animals, are rendered innocuous to a great extent by the forced separation of the fry and are mitigated by the availability of other food.

The current being wholly internal, and its main component circular in its course, it does not force the fry strongly to one side nor allow them to remain in one place as does the tidal current passing through the inclosure. The pressure of the current against the sides varies, of course, with the rapidity with which the outside water is drawn into the car, with the extent of the area through which the water can pass out, and with the rapidity of the current. Since any or all of these factors can readily be controlled there is no difficulty in obtaining a proper adjustment of current for the requirements of particular cases.

Stagnation is prevented even when no new water is admitted from the outside, for the water in the car is constantly being turned over and the lower strata brought to the top and aerated. When, therefore, the water of a car of considerable size is kept cool by being sunk into the ocean and shaded from the sun and is continuously forced to the surface so as to be relieved of waste gases as well as recuperated with oxygen, there is comparatively little need of continuous or frequent renewal. It is at least reasonable to suppose that, in what we may call (after Birge) the "respiration" of a small inclosed body of water containing a considerable quantity of animal life, the elimination of the waste or toxic gases is necessary, and that aeration which is accomplished by forcing more air into the water only partially fulfills the requirements of respiration. The analogy with the physiological process of respiration would seem to be real. In case of small, very thin, flat animals, where the ratio of surface to the bulk is large, respiration may be continuous and direct without special internal apparatus, and, likewise, shallow water with a large expanse of surface has been found by experiment to need no aeration in order to maintain animals alive for a long time. On the other hand, in bulky animals, the respiratory apparatus provides always for the elimination of gaseous products of metabolism as inevitably as it provides for the acquisition of oxygen. Therefore the bringing of the lower strata of water continuously to the surface fulfills two necessary requirements.

For keeping larval forms which are not exceedingly minute, windows covered with screens about 16 meshes to the inch in the bottom of the cars allowing for intake, and similar ones in the sides for the exit of water, are satisfactory. A much finer mesh can be used in this case than would ordinarily be practicable, because the water is drawn in through the bottom screens with considerable force by the upward tendency of the current. It is possible by means of a filter device, which will be described hereafter, to hold fry which would pass through even very fine screens.

The rotary upward current keeps the particles of food suspended in the water even when artificial food heavier than water is used. When, on the other hand, a pelagic live food is used, it is also, of course, readily available, because it is kept in motion and suspended. The important problem of the distribution of food for pelagic forms is solved by this method in a most satisfactory manner.

ADAPTABILITY OF THE METHOD.

Before describing the apparatus as at present installed at our station, where it is applied to the hatching and rearing of young fishes and invertebrates, a word should be said to indicate its general adaptability to various requirements. In any protected body of water, whether river, lake, pond, or in the ocean itself, the apparatus can be quickly and cheaply installed. For experimental work the containing cars may be small. Dr. V. E. Emmel, by use of this method, succeeded for the first time in the difficult task of making mutilated lobsters of the first stage live to regenerate their appendages. His apparatus consisted of an ordinary "paper" bucket provided with screens and the apparatus for keeping the water in motion. On the other extreme the units in our regular installation at Wickford are square boxes measuring 10 feet on a side and 4 feet in depth, with capacity approximately 12,000 liters (fig. 4, 5, 6, pl. XCI, XCII). The capacity of a plant of this sort is capable of unlimited extension by the addition of units. At present the plant at Wickford has a capacity of 24 units of the size mentioned. The method is capable of application to aquatic animals, fresh water or marine, varying in size from those literally microscopic to those of a foot or more in length. We do not

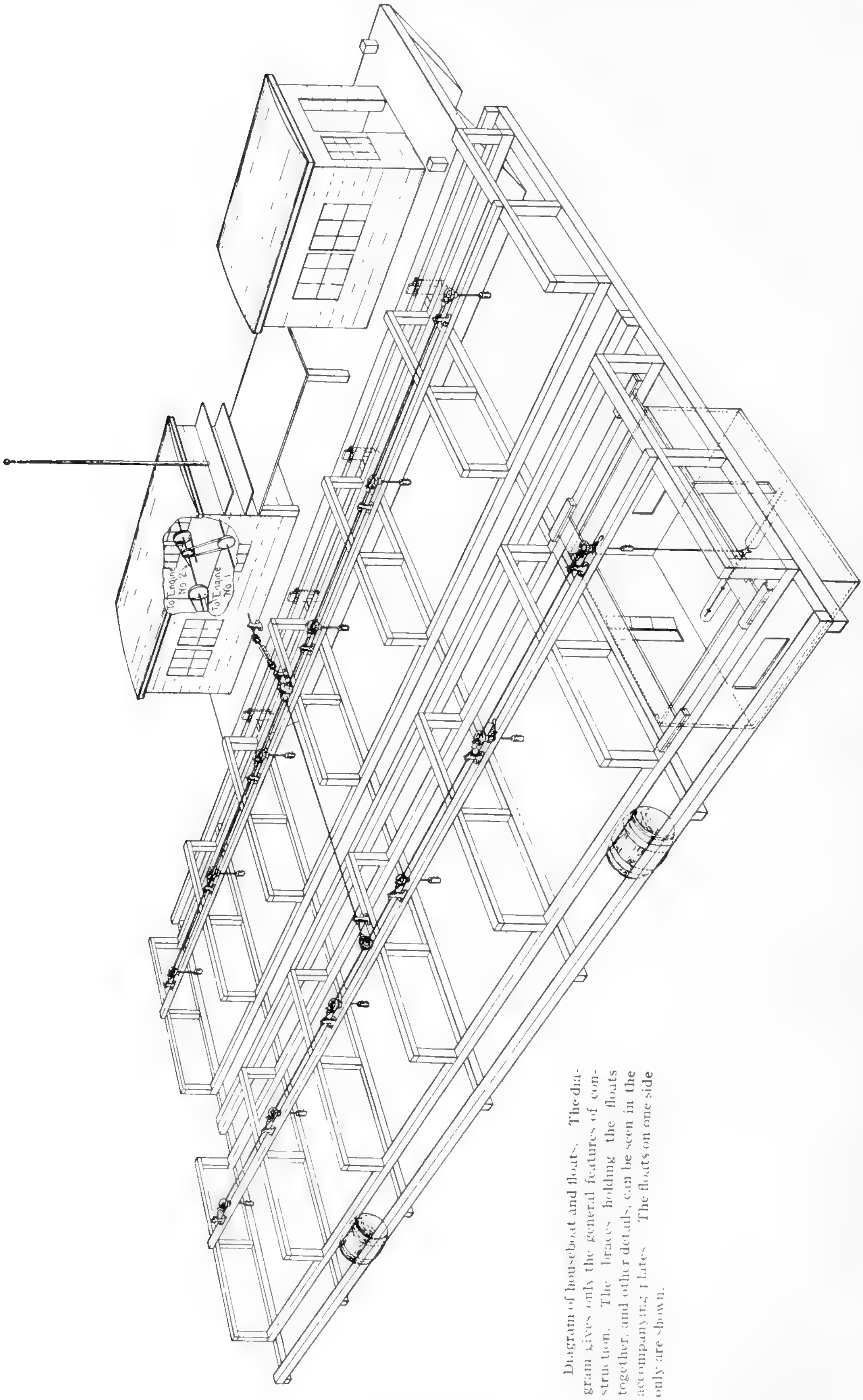

Diagram of houseboat and floats. The diagram gives only the general features of construction. The braces holding the floats together, and other details, can be seen in the accompanying plates. The floats on one side only are shown.

foresee that there are any strictly aquatic animals the requirements of whose young may not be fulfilled by means of this method.

We have developed and applied the method mainly in connection with the hatching and rearing of larval lobsters, but we may assert, without fear of contradiction by anyone familiar with the rearing of lobster fry, that we have done this not because of the comparative ease of rearing lobsters. In the case of all species of fishes which we have attempted to rear the problem is easier than in the case of lobsters.

APPARATUS.

GENERAL DESCRIPTION.

The apparatus as at present installed has proved capable of rearing the larval and young stages of fishes and of invertebrates belonging to several different groups. The main features are as follows: A houseboat consisting of two decked pontoons 4 by 4 feet square in section and 50 feet long held 8 feet apart, the intervening space decked and covered by two houses 10 by 10 feet square and 10 by 20 feet, respectively, flanked on either side by two floats attached to the houseboat and made of 6 by 6 inch spruce timbers bolted together and buoyed up by barrels. The spaces between the timbers of the floats are divided into areas 12 by 12 feet, to contain the hatching cars, and into alleyways about 2 feet wide, to contain the supporting barrels. (See diagram, p. 766, and fig. 1, 2, 3, pl. XC, XCI.)

The inclosures for confining the fry are in the form of 10-foot square boxes (fig. 5, pl. XCII) having two windows in the bottom and two windows in two sides, the windows screened, in the case of lobster fry and very small fishes, with fine-meshed woven bronze wire.

In each box or car a pair of propeller blades, adjustable to various angles, are horizontally placed, attached to a vertical shaft with proper bearings (fig. 4, pl. XCI; fig. 6, pl. XCII; fig. 18, pl. XCVIII). By the revolution of the propeller blades the water is kept in circular and upward motion (fig. 4). The propeller shaft carries at its top a gear which engages a similar one with half the number of teeth borne on a horizontal longitudinal driving shaft. The paddle shaft can, however, be instantly thrown out of gear by a lever (fig. 22, pl. C). The longitudinal shaft transmits the power to all the propellers in one float (fig. 2, 3, and diagram). It receives its power from a shaft running transversely across the float, the two shafts being connected by mitered gears (fig. 4). The transverse shaft of the float is connected to a similar one across the houseboat by a set of universal ball joints and an extensible shaft and sleeve device, invented for this particular purpose, which allows for several inches of variation in the length of the shafting system (fig. 17, pl. XCVIII). The transverse shaft on the houseboat runs through the side of the house and inside the latter is connected with the engine by two sets of pulleys and belts which greatly reduce the speed (diagram, p. 766).

A small gasoline engine furnishes the power. The engine speed of 324 revolutions per minute is reduced to about 36 revolutions per minute in the transverse shafting; then, by gears, to 18 revolutions in the longitudinal shafting, and to 9 revolutions per minute for the propeller blades within the boxes.

Four horizontal driving shafts running lengthwise of the float are each 63½ feet long. The transverse shafts connecting these back to the engine have a combined length of 43 feet. The four large floats are only skeletons in structure. Both they and the houseboat to which they are attached float upon the water and are subjected to considerable motion from the waves and from the swells of passing vessels. A too rigid construction, therefore, is not permissible. Indeed, a friend of the station who is familiar with mechanical construction facetiously observed that any reputable engineer to whom we might submit the plans of our apparatus would without hesitation assert that it probably would not work. However, it runs continuously with hardly an hour of interruption for three or four months at a time.

Several devices have been adopted which together make sufficient allowance for the inevitable rocking movement of the floats and for the warping of the light timbers, viz, comparatively light shafting (1 inch), which in long pieces is flexible; adjustable hangers; large-tooth cast gears; and the sliding shaft and universal joint which has been mentioned. No trouble with the running of the apparatus has ever arisen from the motion of the water, though the latter is sometimes strong enough to break out the screen windows.

DETAILS OF STRUCTURE.

Houseboat.—A brief description of the houseboat with its materials and dimensions is as follows: Two pontoons 52 feet long, 4 feet wide, and 4 feet deep, of 3-inch hard pine calked, completely decked with 2-inch hard pine calked; each pontoon with 3 bulkheads and 4 water-tight compartments accessible by hatches, painted all over, copper paint below water line; pontoons placed 8 feet apart securely fastened by crossbeams and heavy knees at each end; houses 10 by 10 feet near each end of the boat, with floors of 2-inch hard pine, roofs, sides, doors, shelves, closets, of North Carolina pine, painted outside, natural-wood finish inside; roof of house 7 feet from floor and having a slight crown, covered with canvas and painted. An annex to the house (fig. 2, pl. xc) on one end, made of lighter material and of the same dimensions, has been added to give additional space for the engines and tools.

Floats.—The four side floats, so-called, are merely skeleton rafts, buoyed with barrels, whose construction may be seen in the diagram and on plates

XCI and XCII. Pieces of 6 by 6 inch timbers, spliced together if necessary, are bolted together to form a rectangle 19 by 75½ feet. Parallel with the long sides and 2¼ feet inside are similar timbers, running the whole length of the raft. This makes an alleyway on each side for the supporting of barrels, and the spaces between the barrels are available for small rearing boxes used in preliminary experiments. Across the inner long timbers are placed 6 by 6 inch beams at intervals of 12 feet, dividing the whole raft into six compartments 12 by 12 feet square for the reception of the rearing cars. Except for occasional spaces this completes the lower part of the raft.

Upon these beams short vertical pieces are set at the corners of the car pools to form a rest for the seven upper crossbeams which run parallel with the lower ones (p. 766, and fig. 3, 4, pl. XCI). These upper crossbeams of 4 by 6 inch stock support a longitudinal shaft beam, also 4 by 6 inches, which runs the whole length of the float through the middle and upon which are fastened the shaft hangers.

The two floats on either side of the houseboat are fastened rigidly together with bolted timbers. The inside floats are attached to the houseboat by means of D irons and eyebolts to allow about a foot of up-and-down motion. The floats are built comparatively light and of cheap wood, in view of possible future change of plan as a result of experience.

Rearing boxes.—The rearing boxes are square, made of ⅞-inch spruce tongued and grooved boards, nailed to a 2 by 3 inch frame with galvanized nails. The inside dimensions are 10 by 10 by 4 feet. The angles between adjacent sides and between the bottom and sides are truncated by boards 9 inches wide and beveled on the edges (fig. 6, pl. XCII; fig. 13, pl. XCVI). The vertical corner frame pieces are left projecting above the top of the box about 2 inches, to serve as corner posts for fastening the box in place. Ring bolts are put into the four lower inside corners of the box for use in raising the box for cleaning.

Window cases 9 by 36 inches are placed on two opposite sides of the box to receive the movable window frames (fig. 6, pl. XCII; fig. 10, pl. XCIV). Two similar removable window frames 22 inches square are placed in the bottom about 3 feet from the diagonally opposite corners of the box (fig. 6). The size of the mesh in these screen windows varies, according to the size of the fry under experiment, from 16 to 2 meshes to the inch. The material is usually woven bronze or copper wire or galvanized "iron."

In the middle of both sides of the box not having windows a broad slot is cut from the top to within about 8 inches from the bottom. It allows the box to be raised above the water, even though the shaft beam is low (fig. 5, 6, pl. XCII). When the box is down the doors (seen in fig. 9, pl. XCIV), which are fastened on the side of the slot referred to, are fastened shut by strong outside buttons.

It should be said here that this construction was adopted to save rebuilding the floats which had formerly held canvas bags, in which case the low shaft beam was not in the way. In the case of new construction, the shaft beams should be high enough to escape the box when the latter is raised out of the water (fig. 5, pl. XCII).

The boxes are buoyant and have to be forced down into position, where they are held fast by two planks across the top at the end of the box (fig. 4, pl. XCI). The planks are mortised into the corner posts before referred to, so as to prevent lateral movement, and are fastened down to the beams of the float by heavy adjustable cleats secured by bolts (fig. 4, pl. XCI; fig. 9, 10, pl. XCIV). The boxes are painted inside and out.

When a box is to be raised, the cleats are loosened, the planks removed, and ropes from the drums of a transportable windlass are hooked into the ring-bolts of the bottom corners (fig. 9 to 12). The doors are then opened and the hand windlass put into operation. One man has raised a box alone in fifteen minutes, and two men in five minutes. These boxes, the windlass, and many other things were designed and constructed by the superintendent, Mr. E. W. Barnes.

Propellers.—The size and shape of propeller blades found to be most satisfactory vary according to the requirements of different fry. The form of those most used for lobster fry is shown in figures 6, plate XCII; 8, plate XCIII; and 18, plate XCVIII. They consist of two wooden blades, each 4 feet 2 inches long and 8 inches wide at the base, tapered to 5 inches at the apex, and painted all over. Along the middle line the thickness is about 1¼ inches, but from this to either edge is a long bevel which leaves about ½ inch at the edge (fig. 8). Each blade is fastened with iron straps to a piece of galvanized gas pipe, which is screwed into a four-way cross coupling (fig. 18). The latter admits also the vertical gas-pipe shaft running upward toward the gears and a short vertical steel shaft below which sets into a socket consisting of a short piece of large gas pipe fastened to the bottom of the car by a flange. This serves as a lower bearing or guard to the propeller shaft (fig. 18).

The upper part of the propeller shaft is continued by means of couplings through the longitudinal shaft beam and carries a mitered gear at the top (fig. 14, pl. XCVI). In order easily to disconnect and take out the propeller a heavy iron sleeve coupling is inserted into the propeller shaft. The two pieces of the latter are held into the sleeve coupling by set screws (fig. 19, pl. XCIX). As the set screws would be too heavy for galvanized piping, the lower part of the propeller shaft is continued upward by means of a piece of ordinary cold-rolled steel shafting (fig. 19). This is more easily shown in the figures than described.

Driving shafts and gears.—The gear on the top of the vertical propeller shaft engages a similar gear with half the number of teeth on the longitudinal driving shaft (fig. 21, 22, pl. C). The latter is supported above the shaft beam by adjustable hangers. All the gears are cast instead of cut and have large teeth (fig. 20, 21, 22). For our purposes they are probably more satisfactory, and are certainly much cheaper, than cut gears. A nice adjustment is not necessary, and the speed of all the shafting is low, being 36 to 18 revolutions for the horizontal shafts and 9 for that of the propeller.

The longitudinal driving shaft connects by means of mitered gears to a transverse shaft running back toward the houseboat and engine (diagram, p. 766; fig. 4, pl. XCI; fig. 20, pl. XCIX). Between this and the transverse shaft of the houseboat is a pair of ball joints of the common type and the peculiar extension device referred to before (fig. 3, pl. XCI; fig. 17, pl. XCVIII). The latter consists of a sleeve made of two heavy castings fitting loosely over two pieces of square shafting. The two sleeve castings are provided with flanges and are held together by screws, and, to avoid their accidentally slipping off into the water, one end is made fast to the shaft with set screws. Several holes are bored through the sleeve for convenience in oiling. This device allows the square shafting to slide back and forth in the sleeve easily and it has the advantage of being very cheap. It is also very strong, because the shaft has a bearing on the sleeve on all four of its surfaces.

Shafting, pulleys, and engine on houseboat.—The transverse shaft on the houseboat connects with that on both pairs of side floats in the manner described, and is itself connected with the engine within the house by two sets of ordinary pulleys and belt drives in which the speed of the engine is greatly reduced. Two engines are set up ready to connect with the shaft, so that if either one gives out the other may be used. The engines are 2½ to 3 horsepower Fairbanks-Morse vertical type of gasoline explosion engines, and have proved exceedingly satisfactory.

Boxes with filters for holding minute larvæ.—As a modification of the usual form of box or car, to be used for rearing larvæ so small that they would go through any screen with meshes large enough to permit an adequate renewal of water, the following has been adopted: The ordinary boxes are carefully calked in all the seams, and their windows, save one of those in the bottom, are covered with canvas. A gravel and sand filter, made by putting about 4 inches of gravel and sand into a shallow box with wooden sides and heavy galvanized ¼-inch mesh wire in the bottom, is placed over the other bottom window (fig. 21, pl. C). When the car is in place, an old-fashioned bucket chain is rigged on the longitudinal shaft, and the water is thus continually lifted and poured into the hatching box through a short trough. The buckets are painted with asphalt inside and the trough is lined with canvas to prevent contamination of the water from contact with metal or wood. The new water is added, therefore, at the top of the box gradually—about 3½ gallons per minute (fig. 14, pl. XCVI; fig. 15, 16, pl. XCVII).

The amount of water passing through the bottom of the filter does not create an appreciable outward current, and, at any rate, the fry are held above the bottom by the upward trend of the current created by the propellers. Two or three cars of this type have been operated for periods of four to ten weeks at a time. Several varieties of very young fishes and larval invertebrates have been reared with highly satisfactory results. Among the many hundreds or thousands of animals only three or four dead specimens of any kind have been observed.

Canvas lining for boxes.—A further modification of this method has been adopted in order to prevent the escape of certain very small animals like crabs, which seek out and crawl into very narrow cracks in the wood. It consists of putting into the box a large canvas bag as a sort of lining and arranging the filter pump as usual (fig. 16, pl. XCVII). This apparatus has also proved satisfactory.

POSSIBILITY OF VARIATION.

So detailed a description of the apparatus as at present installed and in use might without a further word leave the impression that this apparatus alone fulfills the requirements of this general method of fish culture. On the contrary, there is hardly a feature of the whole outfit that has not been represented, at one time or another during our experiments, by other materials or other forms. The present boxes, for example, have replaced bags of canvas and of scrim and bobbinet, not because the latter failed to give good results, but because they were less durable and otherwise objectionable. Three forms of power transmission have been operated successfully during the development of the plant. It is obvious that the gasoline engine might under other circumstances properly give place to a different kind of motive power, such as steam or hot-air engines or electric, spring, weight, or water motors. For use in small experiments weight or spring motors, properly governed for speed, have much to recommend them, for individual cars could be independently operated in various localities without the inevitable expense and annoyances of running the engine and the apparatus for power transmission.

PRECAUTIONS.

There are, moreover, precautions to be taken in the construction of the cars and other devices. New wood, especially pine, and certain metals, particularly copper and galvanized iron, which are frequently used as screens, are apt to injure, and often prove fatal to young animals even when under other circumstances the circulation through the car would be ample. A very striking instance of the effect of small quantities of copper and zinc-plated screening was furnished in an experiment made a year ago at our station by Dr. V. E.

Emmel in rearing fourth-stage lobsters to the fifth stage.[a] Ninety fourth-stage lobsters were put separately into glass jars, one lobster into each jar, and the whole crate of jars submerged in the water about 2 feet below the surface. A screen of woven copper wire was placed over the wide mouth of each jar to keep the lobsters from escaping. All these lobsters were found dead twelve hours later. Galvanized copper wire screen was then substituted in a new experiment and in twenty-four hours the whole lot were dead. Finally a cloth screen of bobbinet was used, and out of 75 lobsters which were fed, only 1 died before moulting into the fifth stage. Of 15 which were not fed 4 died at the end of a month. These difficulties, if recognized, may in most cases easily be overcome.

TESTS OF EFFICIENCY.

The method and apparatus which have been herein described have been developed, as we have said, mainly in connection with the rearing of lobsters through their pelagic larval stages. But as proficiency in this work has increased we have come to realize that the method is equally well adapted to the rearing of a great variety of fishes and aquatic invertebrates.

Hatching and rearing lobsters.—While the hatching of lobster eggs by this method presents no difficulties, and young lobsterlings, after reaching the fourth stage, can also be cared for without the use of special appliances, the larval lobsters, on the other hand, during the three free swimming stages of two or three weeks' duration, seem to incarnate nearly all the perverse and intractable characteristics which, from the view point of fish culture, are difficult to deal with. They are pelagic and are safe only when floating, yet in confinement they persistently tend to go to the sides and bottom of the inclosure. They are comparatively slow of movement and weak in their instincts of self-preservation and of seeking food, yet their most distressing characteristic is cannibalism. A method of artificial culture, therefore, which will successfully cope with the various difficulties involved in the rearing of larval lobsters might, *a priori*, be expected to answer the requirements of the culture of fishes, few of which, perhaps, offer so many difficulties. While the report on the special method of rearing lobsters is given in another paper, it may here be said, as indicating the general efficiency of the plant, that during the months of June and July and the first few days in August of this year we hatched and reared through their successive larval stages more than 320,000 lobsters (counted) by means of the apparatus as above described.

Fishes incidentally reared.—While the apparatus was occupied with the rearing of lobsters, time and car space were not available for experiments on the rearing of fishes, but incidentally it was demonstrated that the young of many fishes would thrive and grow in the cars. Upon raising cars which had been

[a] Report of Rhode Island Commissioners of Inland Fisheries for 1907, p. 104.

down for two or three weeks there were nearly always found in them a considerable number of small fishes of various species. Since all the water of the car must in these cases have entered through the screen windows of $\frac{1}{16}$ inch mesh, the fishes must have come in when they were very small. The following is an incomplete list of these fishes found in the cars.[a] It should also be mentioned that among these fishes and the other young specimens placed in the cars there was no evidence of illness or mortality.

Species.	Size.	Dates.
	Mm.	
Mummichog (*Fundulus* sp.)	5–25	Throughout season of 1907 and 1908.
Silversides (*Menidia* sp.)	4–21	June 27 to July 8, 1908.
Hake (*Urophycis* sp.)	28	July 26, 1907.
Pipefish (*Siphostoma fuscum*).	15	July 6, 1908.
	30	Aug. 6, 1908.
	114	Aug. 7, 1908.
	77	Do.
	144	Aug. 8, 1908.
	66	Aug. 21, 1908.
	73	Do.
Kingfish (*Menticirrhus saxatilis*).	41	Aug. 4, 1908.
Squeteague (*Cynoscion regalis*).	4.2	July 23, 1908.
	19	July 30, 1908.
	12.5	July 28, 1907.
	6.5	Do.
	25	Aug. 8, 1907.
	18	Do.
	20	Aug. 9, 1907.
	29	Aug. 13, 1907.
	31	Do.
	37	Aug. 26, 1907.

Species.	Size.	Dates
	Mm.	
Puffer (*Spheroides maculata*).	4	(?) 1908.
	3.5	July 9, 1908.
	18	Aug. 3, 1908.
Flatfish (*Pseudopleuronectes americanus*).	10–21	From about June 15 to about July 1, 1908, from 10 to 50 were found in every car when raised
Tautog (*Tautoga onitis*)	3.2	July 8, 1908.
	4.8	July 9, 1908.
	20	July 25, 1908.
	11	July 28, 1908.
	20, 18	Aug. 3, 1908.
	20, 24	Aug. 4, 1908.
	12.5	Aug. 7, 1908.
	8, 9	Aug. 9, 1908.
	23, 25	Aug. 10, 1908.
	21, 41	Aug. 11, 1908.
	8	July 28, 1907.
	5.5	July 25, 1907.

From July 6 to the last of August, 1908, small anchovies (*Stolephorus mitchelli*) continually entered the cars through the fine screens. In many instances hundreds of them, from 2 to 20 millimeters long, were found in these cars. In August several cars were fitted out with coarse screens, one-fourth

[a] From data collected by H. C. Tracy.

inch mesh, and several thousands of anchovies entered one of the cars in a single night. Within the cars they lived and grew. Great numbers of very small specimens between 2 and 10 millimeters in length were taken in July. Mr. Tracy points out a fact of particular significance, namely, that in the tight filter cars many specimens from 2 millimeters to 8 millimeters were found which must have been dipped up by the chain of buckets as eggs or as very small fry, since the fry of 10 millimeters are so quick and wary that they would hardly be caught in this way. There is no doubt whatever that the young anchovies of all sizes thrive perfectly well in the cars provided with screens, and also in the filter cars, and it is more than probable that the eggs of this species frequently hatched in the cars.

About 20 anchovies placed in one of the filter cars on July 28, 1908, were doing well at the date of writing (September 19, 1908), and showed a very considerable growth.

Hatching and rearing fishes.—Near the end of the season for rearing lobsters, during the latter part of July, when the pressure of other work was relieved, some of the large cars were reserved for definite experiments to test the practicability of the method and apparatus as applied to the hatching and rearing of fishes. Unfortunately at this time of the year there were comparatively few fishes whose eggs we could obtain, and we were unable, therefore, to exercise much choice in our material.

On July 17 a quantity of eggs of the "silverside" (*Menidia*) were obtained, and, after being fertilized, were put into a car with the filter and bucket-chain rigged as already described. A short-bladed paddle was used like that in figure 22. This was hung about 2 feet from the bottom, the lower bearing being dispensed with.

The egg masses were teased apart into small clusters and placed on a piece of cloth mosquito netting which was tacked to a piece of soaked wood, so as to form a bag, and suspended in the water. The bag thus formed was held extended and kept from collapsing by a coiled piece of insulated electric wire on the inside. (Practically the same method has been used very successfully in the hatching of the flatfish, *Pseudopleuronectes.*) The eggs hatched in about ten days with apparently no mortality. The young fishes readily escaped through the netting and seemed to thrive perfectly well in the car, where they were kept until August 21, when they were transferred to another similar car, which, however, had a canvas lining. Here they have continued to live until the date of writing (September 19, 1908). There has been no evidence of mortality of any kind during the experiment, although little attention has been given to the feeding, and the fry have had to depend upon the living pelagic food which entered with the water from the chain of buckets.

From the time of hatching to the transference of the fry to another car specimens were taken out daily and preserved. The average daily measurements are here given:

	Mm.		Mm.		Mm.
July 26	3.85	August 4	7.90	August 11	8.22
July 27	4.86	August 5	7.70	August 12	8.80
July 29	5.82	August 6	7.76	August 13	9.20
July 31	6.21	August 7	8.32	August 14	8.77
August 1	6.90	August 8	8.00	August 15	9.30
August 2	7.19	August 9	7.98		
August 3	7.68	August 10	8.23		

On the afternoon of July 27 a portion of the eggs which had remained unhatched in the experiment thus described were transferred to another similarly rigged rearing car (known as S 4), and these eggs hatched within the next day or two. The measurements of specimens taken daily from this new car compare in an interesting way with those given in the previous table. Although they came from the same batch of eggs, and differed only in being slightly younger, they grew more rapidly than the first lot and soon so far outstripped those in the original car that the difference was noticeable upon casual observation.

This difference was doubtless due to the fact that the second lot had more to eat because there were fewer specimens in the car, for, as we have said, the fry had to depend for their food upon the pelagic fauna. By towing in these cars with a small bolting cloth net the absence of copepods and larval animals was conspicuous, especially when compared with the towings taken from a neighboring control car which was in all respects similarly conditioned except that it supported no young fishes. In the latter the pelagic life was abundant. It was evident that the swarm of young fry used up the supply of pelagic food as fast as it came into the car.

The following table gives the daily average length of specimens of *Menidia* in this second experiment:

	Mm.		Mm.		Mm.
July 27	4.52	August 3	7.76	August 10	10.04
July 28	4.91	August 4	8.72	August 11	10.34
July 29	5.04	August 5	9.00	August 12	10.12
July 30	6.06	August 6	9.98	August 13	10.74
July 31	5.51	August 7	9.82	August 14	10.21
August 1	6.57	August 8	10.02	August 15	11.72
August 2	7.58	August 9	9.25	August 17	10.26

The regular measurements were discontinued after this date. On September 8 the average measurement was 14.83 millimeters and on September 14, 14.45 millimeters. In all of these measurements different groups of individuals were caught up, and the averages, therefore, seem to show a decrease in size rather than an increase when there is not considerable rapidity of growth.

A few eggs of *Fundulus heteroclitus* were fertilized on July 27 and were placed in the original filter car. They were floated near the surface in a shallow bag of netting somewhat similar to that described in the case of *Menidia*. The eggs hatched on August 5 and 6 and the fry all lived in healthy condition until they were taken out at intervals and preserved. The daily averages of length for the first ten days are as follows:

	Mm.		Mm.		Mm.
August 5	4.92	August 9	5.56	August 13	5.98
August 6	5.07	August 10	5.37	August 14	6.25
August 7	5.40	August 11	5.88	August 15	6.30
August 8	5.35	August 12	5.92		

Specimens of this lot have continued to live in one of the cars until the date of writing (September 19).

On July 17, 56 young toadfish, measuring from 15 to 17 millimeters, which had been raised from the eggs in a small car, were transferred to the original filter car. At more or less irregular intervals during the next four or five weeks specimens were taken out and measured. The following table of individual and average measurements indicates the rate of their growth:[a]

	Mm.		Mm.
July 17 (56 specimens)	15.0–17.0	August 11	26.0
July 30	19.0	August 14	26.5
July 31	22.5	August 21	[b] 19.0–33.7
August 1	18.7, 22.0		

In order to test these cars with as many kinds of fishes as possible, we introduced the young of some other species in lieu of fish eggs, which could not be obtained in great variety at this season of the year. On July 17 a lot of pipefish taken from the brood pouch of a male were put directly into the original filter car. The individuals appeared to be of practically equal length and measured 10 millimeters. They apparently all lived and, like the other specimens in the cars, continued to thrive, showing no sign of disease, until they were taken out, on August 21.

The following data show the rate of growth as indicated by the average sizes at the end of irregular periods. No food was given to them except that which came in with the water by means of the chain of buckets.

	Mm.		Mm		Mm.
July 17	10.0	July 30	44.0	August 15	67.2
July 18	11.4	July 31	46.1	August 20	69.4
July 20	21.8	August 2	52.6	September 8	[c] 71.3
July 23	24.5	August 6	61.6	September 14	[c] 70.0
July 25	27.5	August 8	58.6		
July 27	26.5	August 11	67.4		

[a] I am indebted for these measurements to Mr. H. C. Tracy.

[b] Average, 30.21 mm. Fifty-four specimens out of 56 put into the car were recovered.

[c] Measurements taken after transference to new car.

On August 21 the remaining specimens were transferred to another filter car with canvas lining, where they remained alive and well up to September 19.

On July 21 another pipefish was caught with a brood pouch full of young which measured 10 millimeters. These young were placed, together with the second lot of *Menidia*, in a filter car rigged with a chain of buckets like the original one. These specimens lived and thrived equally well. No food was given them except on one or two occasions. The data of growth are as follows:

	Mm.		Mm.		Mm.
July 23	10.7	August 6	37.8	September 8	59.0
July 27	19.0	August 8	41.8	September 14	62.8
July 30	24.0	August 11	41.9		
August 3	31.4	August 15	45.2		

On August 8 and 10 a number of young bluefish were caught in the seine and were placed in one of the rearing cars which had been provided with coarse window screens of ¼ inch mesh. When put into the car there were already present in the water several thousand young anchovies, about 20 to 25 millimeters in length. These the bluefish ate during the first day. On several occasions a few *Menidia* and *Fundulus* were given them to eat. On August 12 they were given as much raw meat as they could eat, and this they devoured ravenously. They were fed on meat again on August 15 and on *Menidia* two days later. The average size of these bluefish on August 18, about ten days after they were put into the car, was 140.8 millimeters, an average increase of about 10 millimeters. On September 1 they were measured again, having been fed meantime on several occasions with *Menidia, Fundulus,* and other small fishes. The average length on this date, September 1, was 174 millimeters. This measurement and the two which follow were taken from the nose to the end of the fin rays, whereas the previous measurements were taken from the nose to the base of the fin rays. Between September 1 and September 8 the specimens were not fed. On September 8 they measured 175.1 millimeters, showing an increase during seven days of 1.1 millimeters.

On September 8 a quantity of live fishes was put into the car to serve as food for the bluefish, and during the next seven days the bluefish showed an average growth of about 10 millimeters, the average length being 184.3 millimeters.

The filter cars which have been described, and in which the previously mentioned eggs and young fishes were kept alive, have also proved themselves capable of maintaining a considerable variety of other fishes and invertebrates, among which are the following: Tautog, flatfish, anchovy, oysters (both old and young), scallops, anomia, crabs, barnacles, polyzoans, *Botryllus*, *Nereis* larvæ, etc.

Crabs and scallops.—On August 2, 1908, a very large number of zoeæ and megalops of the oyster crab were found floating at the surface of the water. A considerable number were caught with a net and transferred to one of the filter cars, in which they have remained ever since. On September 19 their average measurements were, length 8⅝ millimeters and breadth 10¼ millimeters (Mr. Sullivan).

On August 3, 13 scallops, measuring between 45 and 65 millimeters in length, were placed in the second filter car after having a deep notch filed in the shell so that the rate of their growth could be determined accurately. On September 18, 11 of these specimens were taken out of the car and were in excellent condition. The notch and the zone of new growth indicated precisely the size and shape of the shell when the scallop was placed in the box. The increase in length was about 20 per cent. The following table gives the measurements of these specimens:

Length, Aug. 3.	Length, Sept. 18.	Length, Aug. 3.	Length, Sept. 18.
Mm.	*Mm.*	*Mm.*	*Mm.*
50	60	51	60
44	55	52	64
47	60	46	56
60	68	52	62
45	55		

GENERAL APPLICATION OF THE METHOD IN AQUICULTURE.

There are two great problems in the general question of fish culture to the solution of which the method herein described contributes:

First, to the problem of hatching and rearing to an optimum size for liberation quantities of fishes of economic value for the direct purpose of stocking the waters. The comparative ease of hatching eggs of most fishes has resulted in the establishment of many prolific hatcheries; on the other hand, the number of establishments capable of rearing young fishes and the number of species so reared in confinement are few. A method of culture, therefore, which is capable not only of hatching but of rearing large numbers of fishes of widely different species marks, we hope, a new step in fish culture.

The second general problem is the ascertainment of the appearance, habits, requirements, and rate of growth of economically important fishes in their early stages of post-embryonic development. As contrasted with the vast amount of investigation of the embryonic stages of development, which has been facilitated by the abundance of readily available material in the form of eggs of all stages, the data relating to the post-embryonic development are almost entirely lacking. Even the identification of the young of many food fishes abundant in their spawning season is at present impossible. A method by which eggs of widely different species may be hatched and reared and by which the unidentified fry caught at large may be reared under observation will be able, we hope, to furnish the necessary material for the solution of this general problem.

APPLICATION IN TRANSPORTATION OF LIVE FISHES.

In our opinion the essential principle upon which this method of fish culture is based will be found of value in solving the problem of the transportation of live fishes and, moreover, the method and even a portion of the apparatus can be modified and adapted so as to carry this principle into effect. The principle, is, briefly, to provide at the start native "unmodified" water; to maintain a proper temperature and density, and in some cases current; to secure the continuous "respiration" of the water, including the egress of waste gases of the metabolism of contained fishes and often of bacteria as well as the access of oxygen, and to avoid contact with injurious metallic substances.

To carry into effect this principle we propose the following method: To use for transportation an iron tank enameled on the inside with a vitreous substance in order to prevent contact of the water with the metal; to use only water dipped from the water in which the animals have been living, in order to insure its proper constitution; to surround the tank with a jacket into which ice or warm water can be put to control the temperature (for many animals, at any rate, both among fishes and invertebrates, we have found by experience that a low temperature is a very important factor in maintaining life when the animals are crowded into a small amount of unrenewed water); to provide both the current and the continuous respiration by installing a propeller device of enameled iron kept in motion by means of a spring motor.

FIG. 3.—Starboard side, looking aft, inside float. Shafting system and general arrangement of cars

FIG. 4.—Car with propeller in motion. From propeller the shafting may be followed back (1-8) to the universal joint. 1, propeller shaft; 2, sleeve coupling; 3, longitudinal shaft; 4, adjustable shaft hanger; 5, gear trains from longitudinal to transverse shafts; 6, transverse horizontal shaft of float; 7, shaft hanger; 8, ball joint connecting shaft with that of house boat; 9, edge of rearing box; 10, brace across corner of rearing box; 11, holding-down plank mortised into corner post; 12, shaft beam.

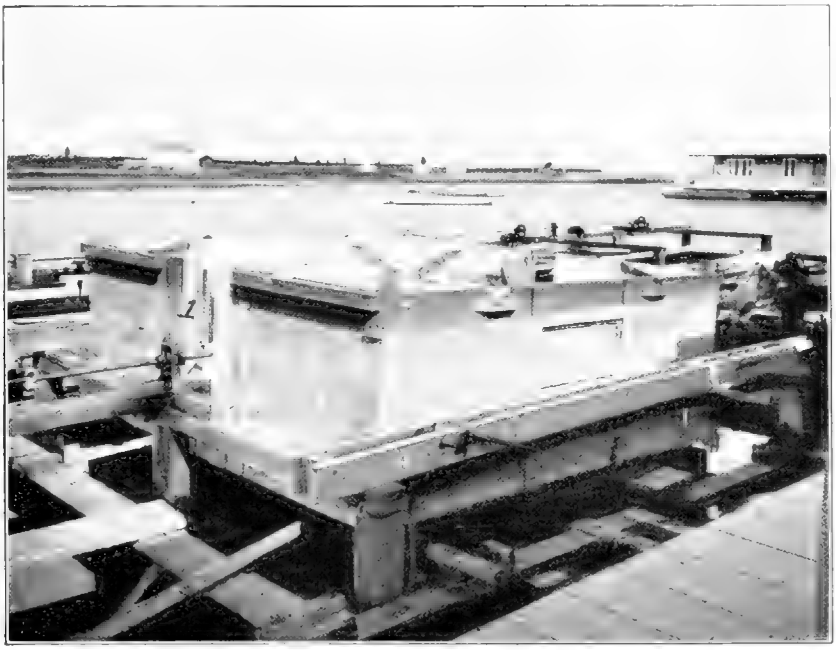

FIG. 5.—Rearing car raised and held up by portable windlass. 1, slot in end of car through which the longitudinal shaft runs when car is raised; 2, longitudinal shaft; 3, side window of car; 4, portable "horse" and windlass.

FIG. 6.—Interior of rearing car, and propeller. 1, slot in end of car; 2, doors for closing the slot; 3, side screen windows; 4 and 5, bottom windows; 6, box covering gear trains; 7, transverse shaft; 8, longitudinal shaft; 9, towing car. The arrangement of shafting on farther float can be seen

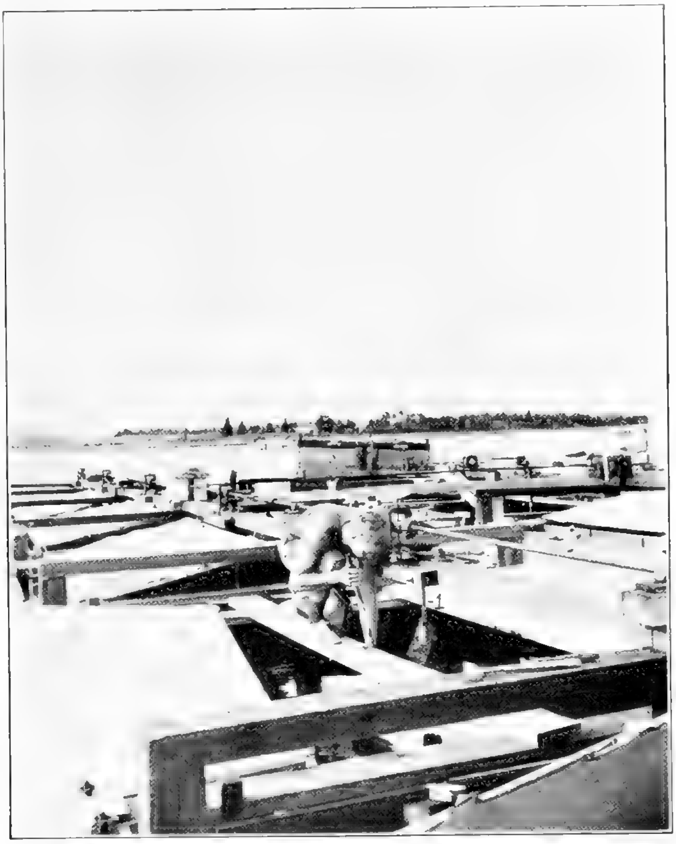

FIG. 7.—Lifting the disconnected propeller out of the water. The upper portion of the shaft with the sleeve coupling is seen at 1.

FIG. 8.—The propeller removed, showing disconnected shaft. The upper part of the shaft and the coupling are faintly visible under the shaft beam. The photograph shows well the size and shape of the propeller blades

FIG. 9.—Cleat at the end of the holding-down plank, showing the detail (1).

FIG. 10.—The cleats being removed, the car rises part way by its own buoyancy. Opening doors of the slot at end of car to admit the longitudinal shaft beam allows the car to be entirely raised. 1, cleat; 2, holding-down plank; 3, longitudinal shaft beam; 4 and 5, side windows.

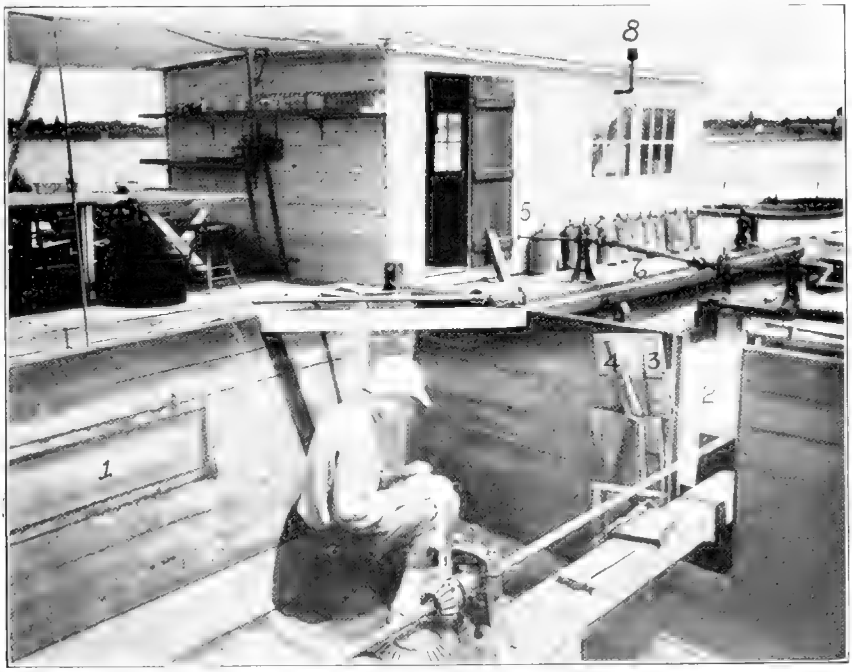

FIG. 11.—Interior of rearing car. Preparing to calk small cracks before lowering the car. 1, side window; 2, end slot; 3, doors for same; 4, buttons to hold doors shut; 5 and 6, the transverse shaft, universal joint, and sliding sleeve; 8, exhaust and muffler.

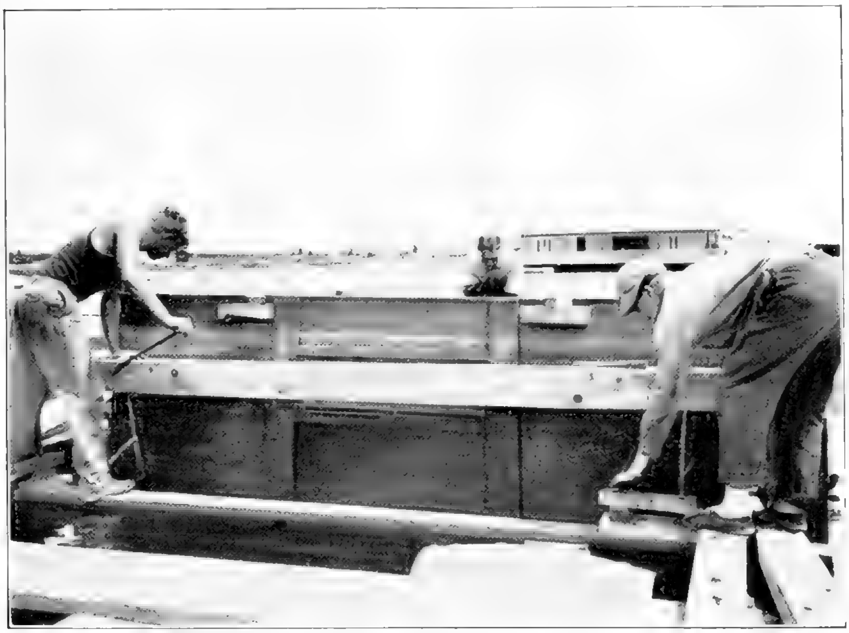

FIG. 12.—Raising the car by means of windlass. Ropes from the drums of the windlass are fastened by hooks to rings in the lower corners of the car.

FIG. 13.—View of interior of a car, showing filter of gravel and sand placed over one of the bottom windows. Arrangement described in text for rearing very minute larvæ or those for which screen windows are dangerous. The car is calked tight; water is poured over the top by bucket chains (see fig. 15, pl. XCVII) and its only exit is through this bottom filter.

FIG. 14.—"Filter car" in operation. Short propeller hung about 18 inches below the surface. 1, trough with canvas lining for conducting incoming water; 2, floating shallow bag of scrim used in hatching certain fish eggs. The arrangement of shafts and gears shows well in the figure.

FIG. 15.—Filter car, same as figure 14, plate XCVI, showing bucket chain in operation. One of the buckets has just emptied itself and the stream of water is faintly shown running into the trough.

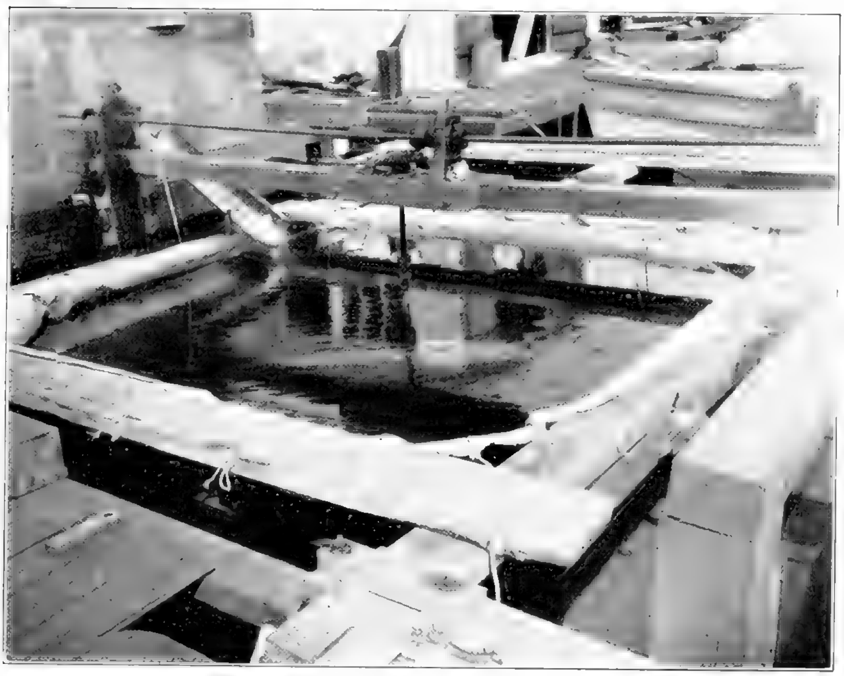

FIG. 16.—Filter car with canvas lining. Chain buckets on left. The propeller blades may be seen in the water.

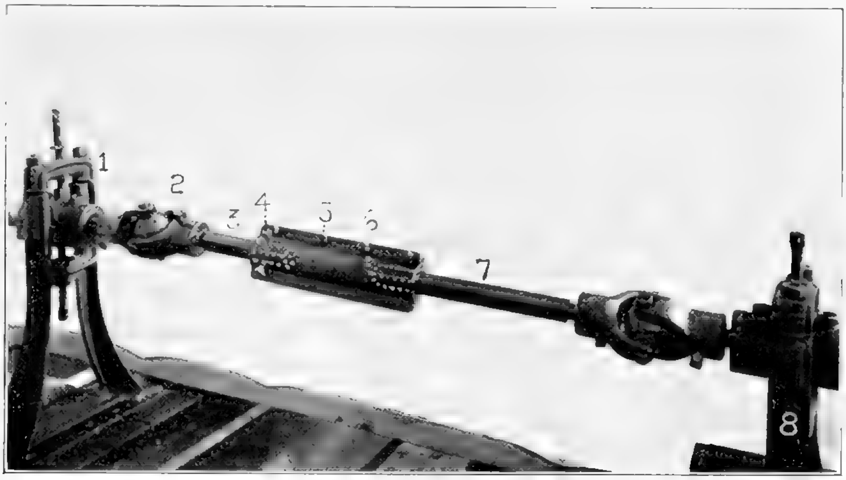

FIG. 17.—Detail of device for extension and universal movement. 1, adjustable shaft hanger on house boat; 2, ball joint; 3, square shafting, fastened by set screws into ball joint at left, and also (4) into sleeve; 4 and 5, screws through flanges of sleeve; 6, oil holes; 7, square shaft which slides in and out of sleeve; 8, shaft hanger upon side float.

FIG. 18.—Detail of lower portion of the propeller shaft and its socket in floor of car. 1, propeller shaft, made of gas pipe; 2, short portion of shaft made of steel, to fit into the socket (6); 3, four-way pipe coupling; 4, gas pipe to which blades are strapped; 5, strap holding propeller blades; 6 and 7, socket and flange; 8, upper disconnected steel portion of the propeller shaft; 9, shaft beam; 10, window in bottom of car; 11, base of propeller blade, showing in section the shape.

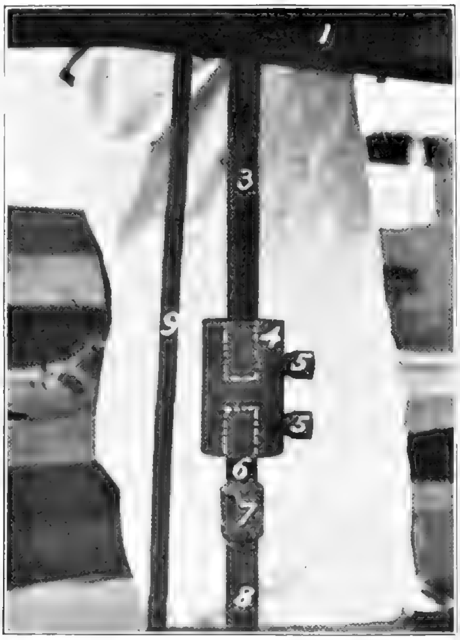

FIG. 19.—Detail of propeller shaft couplings. 1, underside of shaft beam; 3, upper steel portion of shaft, which bears gear on top and enters sleeve coupling below; 4, cast sleeve coupling; 5, set screws holding shafts in coupling; 6, short piece of steel shaft; 7, pipe coupling; 8, lower part of shaft, made of pipe; 9, measuring stick, made of sections 6 inches long.

FIG. 20.—Detail of gears on float at junction of transverse and longitudinal shafts. (Compare fig. 3, pl. XCI.) 1, gear on horizontal shaft from house boat; 2, large gear on longitudinal shaft, reducing speed one-half; 3, gear on the inner end of transverse shaft (4); 4, shaft transmitting power to outer float; 5, longitudinal shaft on inner float; 6, oil box.

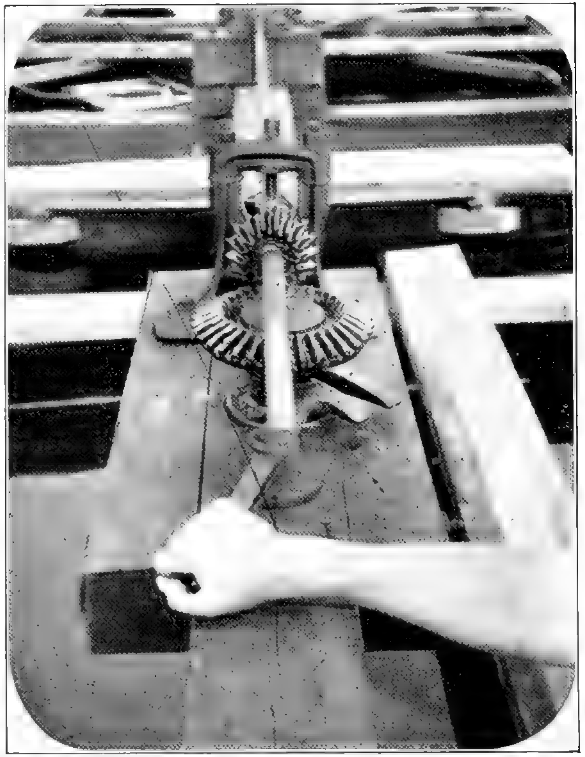

Fig. 21.—Detail of device for throwing propeller in and out of gear. By pulling the lever the propeller shaft and its gear drop as in fig. 22

Fig. 22.—Device for throwing propeller out of gear. (Compare fig. 21.) This figure shows the propeller shaft gear dropped down so as not to engage the smaller gear on the longitudinal shaft.