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A DESCRIPTION OF INTENSIVE CULTURE SYSTEMS FOR THE AMERICAN LOBSTER (*Homarus americanus*) AND OTHER CANNIBALISTIC CRUSTACEANS[1]

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ABSTRACT

The high rates of cannibalism which have been documented for *H. americanus* reared communally dictate that for a majority of the culture period the lobsters should be reared individually, in order to eliminate these losses. Criteria essential to the development of culture systems for the intensive rearing of lobsters and other cannibalistic crustacean species in individual holding compartments are considered. These include the necessity for holding large numbers of individuals in a minimal amount of space, delivery of oxygenated water evenly to each rearing compartment, and removal of wastes. Considerations of space utilization, capital construction costs, and associated components for automatic feeding, maintenance, and harvesting also are discussed.

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Several alternative production systems have been designed. Large prototypes of systems showing considerable potential were constructed and their performance characteristics compared. Preliminary data on the growth of lobsters reared in two of these systems are presented. Several intensive culture systems developed by other researchers also are described. Further analyses should provide the information necessary to assess the economic feasibility of lobster culture.

INTRODUCTION

In the past decade many biological and technological problems involved in culturing the American lobster (Homarus americanus) have been solved. Culture techniques have been developed for the larval and juvenile stages and current research efforts are directed toward reducing cannibalism, refinement of artificial diets, and developing methods of disease prevention. There is general agreement that the major constraint to commercial production is the limited ability to rear large numbers of juveniles to market size, using methods that are both economical and dependable.

The research program at San Diego State University (SDSU), as well as several other institutions, concerns the problems which must be solved before commercially viable lobster farming would be possible. A very large amount of relevant information is now available describing: 1) satisfactory systems for larval culture (Hughes et al., 1974; Serfling et al., 1974a, b; Schuur et al., 1976); 2) feeding requirements, activity patterns, and social behaviors (Krekorian et al., 1974; Carlberg, 1975; Lester, 1975); 3) techniques for mass rearing of juveniles (Van Olst et al., 1975, 1976); 4) optimal feeding rates for larvae and early juveniles (Carlberg and Van Olst, 1976); 5) optimal temperatures for lobster culture (Hughes et al., 1972; Botsford et al., 1974; Ford et al., 1975; Van Olst et al., 1976); 6) diagnosis, treatment, and prevention of diseases (Schapiro et al., 1974; Fisher et al., 1976); 7) methods for analysis of cost-effectiveness (Johnston, 1975); 8) several promising artificial diets (Conklin et al., 1975; Van Olst et al., 1976); 9) successful cross-breeding of H. americanus and H. gammarus (Van Olst, 1975); and 10) the use of thermal effluent as a low-cost, non-toxic source of heated seawater for mariculture (Ford et al., 1975; Van Olst et al., 1976; Dorband et al., 1976).

LOBSTER PRODUCTION PLAN

The results of recent research indicate that a three-phase scheme for commercial lobster production might be appropriate. In the first phase, larvae would be reared in special planktonkreisel culturing containers designed by John Hughes at the Massachusetts State Lobster Hatchery and modified by other investigators (Serfling et al., 1974a, b; Schuur et al., 1976). At 22-24°C, larvae stocked at initial densities of 3,000 per container should yield approximately 2,000 Stage IV individuals.

In the second phase, the small juveniles would be cultured in communal rearing systems for up to six months. The advantages of this approach result from decreased costs in feeding, maintenance, and water distribution to animals held in large communal tanks, as opposed to smaller, individual containers. During this period, even with high levels of supplemental feeding, relatively high losses due to cannibalism can be expected (Van Olst et al., 1975). However, these losses come at a time early in the growth of the lobsters and are tolerable in terms of labor and feed expenditures at this stage in the culturing process. Lobsters of 5 mm carapace length stocked at densities of $100/m^2$ in raceways with plastic honeycomb substrates which provide many crevices and shelters, should yield 40 $lobsters/m^2$ with an average carapace length of 20 mm at the end of the six-month rearing period. Cannibalism may be an advantage, since it is a process of biological selection which eliminates those animals least well adapted to the artificial culture environment.

At the end of the communal rearing period, each survivor would be so large that further losses due to cannibalism could not be tolerated from an economic standpoint. Thus, in the third phase lobsters would be cultured to final market size in a system incorporating individual rearing containers, in order to eliminate losses due to cannibalism.

CULTURE SYSTEMS FOR THE INDIVIDUAL REARING OF LOBSTERS

Several different methods have been developed for culturing lobsters individually. All of them provide a separate compartment for each animal, a constant supply of oxygenated seawater to each individual, a method of removing particulate and dissolved wastes, and in general an environment which will promote rapid, uniform growth and high survival. Once the criteria for providing high water quality are met, the most important requirement is the amount of space provided for each animal, in terms of cross-sectional bottom area. Preliminary results (Van Olst, 1975) indicate that growth and survivorship are directly related to the size of the rearing container, and are seriously reduced when insufficient space is provided. Growth is affected by a reduction in the length and weight gains at each molt, and also by a lengthening of the intermolt period. A detailed, 18-month study of the effects of confinement on lobster growth was recently completed at our Redondo Beach laboratory. The results suggest that the width of a rectangular rearing container must be at least as large as the total length of the lobster in order to avoid significant reductions in growth rate. The individual rearing systems developed at SDSU and described in this paper incorporate this design criterion.

Care-o-Cell System

The care-o-cell (Fig. 1) consists of a matrix of perforated cages which rotate around a center axis and float at the surface of a larger circular tank similar to a sewage treatment primary clarifier. Each rearing compartment passes beneath radius arms suspended over the tank. The radius arms supply oxygenated water, and in a commerical system would be implemented with automatic food delivery hoppers and a walkway to allow human access for stocking, harvesting, and other maintenance operations.

Several prototypes of this system have been constructed and function satisfactorily. A smaller version, measuring 121.9 cm in diameter and 37.3 cm in height, incorporates a central standpipe which maintains the water at a depth of 33.0 cm and also serves as the rotational axis for the floating rearing compartments. This matrix of compartments consists of 156 cylindrical cells, 5.0 cm in length and 6.6 cm in diameter. The bottoms of the cells are covered with fiberglass screen of 1.5 mm mesh. A radius arm with 15 water jets of 1 mm diameter supplies seawater at an angle, and the resulting force causes the floating matrix to rotate at approximately 1.8 rpm. In addition to the surface supply, seawater is also introduced below the floating matrix by peripheral water jets which rotate the water mass in a direction opposite to the matrix. Turbulence is generated at the water-screening interface at the bottom of the rearing containers which increases oxygen diffusion and aids in removing particulate waste. The juvenile lobsters appear to adapt to the periodic jet of seawater from above, and to the rotation of the container. This system has been used successfully in culturing small juveniles for several years. A similar, larger tank also has been used in studies with larger juveniles. This tank measures 152.4 cm in diameter by 74.9 cm in height and is filled to a depth of 67.3 cm. The floating matrix consists of 90 cylinders, 10.1 cm in diameter and 10.1 cm in length, and is rotated by water jet pressure at approximately 2.0 rpm. No subsurface water jets were used in this system, and as a result more frequent manual cleaning has been necessary.

Based on promising results with these smaller units, a larger care-o-cell capable of holding lobsters of market size was designed and constructed. The holding tank is 304.8 cm in diameter by 36.8 cm deep, and is filled to a depth of 26.6 cm. An access walkway spans the tank, and also holds two radius arms which distribute oxygenated seawater through 14 supply jets. A flow rate of approximately 60 liters/min rotates the floating culture containers at .75 rpm, as described for the smaller units.

A new type of individual rearing container has been developed for this system, consisting of vacuum-formed plastic baskets with perforated sides and bottoms. White ABS plastic sheet stock (3 mm thick) is perforated with 5 mm holes on 8 mm staggered centers using a large hydraulic punch press. These perforations provide an open area of 28.5 percent. The perforated sheet is placed over a positive-image wooden mold in a heated vacuum-forming chamber. An expendable, thin plastic cover sheet is necessary to maintain a vacuum in the chamber, due to the perforations in the ABS plastic. The finished product is a rectangular plastic rearing container 35.4 x 15.2 cm deep, perforated on all four sides and on the bottom. Expansion of the plastic during the forming process, especially in the corners of the container, causes the 5 mm perforations to expand to 7-13 mm in diameter, but this does not seem to reduce the structural integrity of the container. Flotation is provided for each container by cementing strips of styrofoam to the upper edges with silicon rubber adhesive.

The holding tank can accomodate 48 culture containers. This allows utilization of only slightly more than one-half of the area of the holding tank, due to space occupied by the flotation strips and problems in the positioning of the rectangular containers in the circular unit. In larger versions it should be possible to develop rearing containers which utilize the available space more effectively.

The large prototype has performed well for over one year. Adult lobsters weighing approximately 500 g have survived, molted and exhibited normal rates of growth in this system.

Flushing Tray System

The development of the flushing tray system has been a joint effort between our research group and Dr. David E. Aiken of the St. Andrews Biological Station in New Brunswick, Canada. The system (Fig. 2) consists of a fiberglass tray which is flushed periodically to remove wastes from lobster holding cells constructed of ABS or PVC plastic. Seawater for oxygenation is introduced continuously by a trough or pipe along one long wall of the tray, flows through the perforated walls of each rearing container and exits through an overflow trough or collection pipe along the opposite wall. The short partitions, oriented 90° to the long perforated partitions, are made of solid, unperforated plastic. The bottoms of the rearing containers are covered with perforated screen and are elevated slightly off the bottom of the tray. Once per day, or more frequently if necessary, large valves are opened at the end of the flushing tray. Because the short, solid partitions act as dams to the longitudinal flow of seawater in the tray, all the water flow is forced down through the perforated bottom of each rearing container and then moves rapidly across the bottom of the tray. This rapid flow has a scouring effect on the bottom screening and on the bottom of the tray, so that the entire system is almost completely self-cleaning.

Two prototype flushing tray systems have been constructed and evaluated. The first model, constructed of epoxy-coated marine plywood, measures 244.5 x 78.1 x 16.8 cm deep. It is filled to a depth of 11.5 cm, and contains 72 PVC rearing compartments 17.8 x 12.7 x 12.7 cm deep. The compartments are arranged in three matrices of 24 cells each, and the bottoms are made of 3 mm mesh polyethylene screening. Two plastic toilet valves of 50 mm diameter are opened daily to flush the entire tray; this requires less than 120 seconds.

The flushing action is extremely efficient in removing wastes, but infrequent manual cleaning also is necessary to remove attached algae and bacterial slime.

Comparisons were made between growth rates of lobsters held in the care-o-cell, and in the flushing tray prototype. Growth also was measured for juvenile lobsters held in one-liter solid-bottom polyethylene culture containers commonly used in rearing experiments at several laboratories. Results are shown in Figure 3. Regression analysis and analysis of variance of final sizes attained indicate no significant differences in growth rates ($p > .05$) among the three systems.

Based on the encouraging results obtained with the first flushing tray prototype, a larger system has been developed. This consists of a fiberglass flushing tray of approximately the size that could be utilized commercially (48.7 x 121.9 x 17.5 cm deep). Ten of the trays are positioned in two cantilevered steel racking systems, as indicated in Figure 2. Water depth is held at 14.0 cm. Each tray holds 96 individual rearing containers which measure 28.9 x 19.4 x 17.5 cm deep. The containers are arranged in eight matrices of 12 compartments each. The perforated plastic walls parallel to the long axis of the tray have 5 mm holes on 8 mm staggered centers to yield an open area of 28.5 percent. The bottoms of the containers are covered with 3 mm mesh polyethylene screening. The time required to flush one tray is approximately 180 seconds. The water removed from the tray is briefly stored in a collection sump, and then filtered and returned to the tray in approximately seven minutes.

The normal flow rate supplied to each tray is 24 liters/min. Dye studies have been done in a full-scale plexiglass model of a cross section of the tray. The input water flows fairly rapidly across the tray and a portion of it reaches the drain system in about 60 seconds. Mixing and aeration of the water appear to be adequate at this flow rate. The flushing tray system appears to be superior to the care-o-cell and several other systems in its ability to hold large numbers of animals in a minimal amount of space, deliver oxygenated seawater evenly to each rearing compartment, and remove wastes rapidly and economically. Furthermore, these shallow, rectangular tanks allow efficient use of space and relatively high carrying capacity in terms of the number of lobsters that can be held.

The flushing tray system is adaptable to support on racks up to approximately 20 levels. Several possible changes in tray design are contemplated, including the incorporation of airlift pumping systems for circulation and oxygenation of the water and the addition of vortex-producing jets below the rearing compartments. Program timers and solenoid valves would flush the trays automatically and sequentially into a common sump where heating, filtration, and water treatment would take place. In a commercial application, special forklifts would drive through aisles between the tray racks to pass food dispersing arms over each tray. As shown in the artist's conception (Fig. 2), we envision a tall, multi-armed forklift device which has food delivery spigots suspended over each rearing compartment at all levels simultaneously on both sides of the aisle between tray racks. As the feeder unit travels down the aisle, a photocell would sense indexing marks on the trays and operate the bank of delivery spigots, which might be kept primed with food pellets drawn from a central hopper by particle fluidization. Eventually an entire warehouse could be fed automatically by one or more feeders controlled by a small computer system, just as automated part retrieval machines are now used to select items stored on any level of large warehouses and deliver these items to the loading dock.

Deep Tank System

Although the care-o-cell and the flushing tray appear to be reliable, semi-automated culture systems for *Homarus*, there are several potential problems with them. The care-o-cell requires a relatively large amount of space, since the animals are all distributed in one layer. The cantilevered tray system solves this problem by supporting the trays at several levels. However, it does so at considerable expense, because a separate tray is needed at each level to hold the rearing containers. We are now evaluating a deep tank system which may provide the advantages of three-dimensional arrangement of the rearing containers at considerably less expense than does the cantilevered tray system.

The deep tank system consists of a large, deep holding tank in which perforated rearing container units are hung vertically, as shown in Figure 4. The containers are lifted vertically out of the holding tank by an overhead winch or gantry so that feeding, stocking, and harvesting can be accomplished. Food is introduced through food injection nozzles which slip through flexible rubber slits molded into the vertical face of each container.

A prototype of this system also has been constructed. The fiberglass holding tank measures 294.3 x 137.1 x 91.4 cm deep. It incorporates 20 vertical container units of 49 rearing compartments which each measure 16.5 x 12.7 x 10.2 cm high. Thus, a total of 980 lobsters can be maintained in the system, which holds less than 4000 liters of seawater.

Growth and survivorship studies of lobsters held in this system are currently in progress. If they prove successful, the deep tank system for individual culture of lobsters will be evaluated on a more detailed basis for its applicability to commercial-scale lobster farming. If preliminary estimates are accurate, extremely high holding densities appear feasible, perhaps as high as 73 kg/m^2 of bottom area, in concrete raceways 3 m wide and 3 m deep.

OTHER INDIVIDUAL CULTURE SYSTEMS

The culture systems presented here compare favorably with several others which have been proposed in recent years. All are capital-intensive, and are conservative of land and labor when compared to the typical methods utilized for rearing of less cannibalistic species in ponds. However, the complexity of the culture systems varies considerably. Table 1 describes some of the advantages and disadvantages inherent in these systems. Perhaps the least complex system is one in which a floating, two-dimensional array of individual rearing containers is placed in an existing body of water. Such an offshore, two-dimensional system is currently under development by Aquaculture Systems, Inc., in Raccoon Bay, Georgia. A three-dimensional array of cages which would be anchored to the ocean bottom, in order to avoid surface weather conditions, was proposed by Bentho-Culture, Inc. (Fig. 5), and also by a European firm culturing *Homarus gammarus*. These underwater systems would be serviced daily by divers. A similar three-dimensional offshore cage system to be serviced from an access pier on the surface was patented by the McDonalds in 1968 (Fig. 6). The principal advantages of offshore systems such as these would be lower initial capital costs, and lower operating costs for water treatment and pumping. However, these may be offset by potential problems related to the lack of control over the environment offshore, the difficulty of stocking, feeding, and harvesting, little control over disease and predators, and potential legal problems involving restriction of public waterways.

The majority of the proposed culture systems for the individual rearing of cannibalistic crustaceans have been developed as onshore systems in order to provide for increased environmental control. As Table 1 indicates, they can be separated into three categories. Two-dimensional systems provide an array of rearing compartments one layer deep. Layered two-dimensional systems arrange several arrays of compartments vertically, but each layer is located in its own separate tray or tank of water, so that each animal has an air-water interface above it. Three-dimensional systems consist of stacks or layers of individual cages which are immersed in one or more deep tanks or raceways.

An example of a two-dimensional system is the care-o-cell. In areas where land value is low enough so that the facility can be spread out to accommodate a single layer of cages, this system offers the advantages of a high surface to water volume ratio for oxygen transfer and convenient and vertically unrestricted access for monitoring, stocking, feeding, and harvesting.

Unfortunately, however, most coastal property in North America is extremely expensive, and it will probably be necessary to resort to vertical use of this land in the commercial culture of lobsters. One method of utilizing the vertical space is simply to arrange the culture trays in vertical racks. One system which is adaptable for this approach is the flushing tray, which can be stacked vertically by means of commercially-available, cantilevered warehouse racking material, as illustrated in Figure 2. This system also provides for relatively convenient access and high surface/volume ratios, but appears to be wasteful and expensive, since a separate tank is necessary for each level. This layered two-dimensional system may be most useful in holding especially valuable animals such as brood stock, which would need to be handled and moved frequently during the culture operations.

The three-dimensional systems appear to offer the greatest savings in terms of requiring little land area, inexpensive holding tank construction, and no need for redundantly stacked water trays. The major disadvantages of relatively low surface area/volume ratios and inconvenient feeding and harvesting can be compensated for, at least in theory, by incorporating several recent technological developments.

For these reasons, there have been a number of three-dimensional individual culture systems designed for Homarus culture in addition to our deep tank system, as well as some which have been developed for Macrobrachium culture.

The development of a vertical silo culture system for Homarus has been funded by Saunders and Associates, Inc., in Kittery, Maine (Fig. 7). Each lobster is held on a circular disc suspended by rods in vertical acrylic tubes. Food is introduced to each level by packing it into recesses formed in the side of a dowel, which is lowered into a distribution tube that has holes at intervals matching the food recesses in the dowel. By rotating the dowel, lobsters in each level of the silo gain access to the food. One disadvantage of this system appears to be the high cost of the acrylic tubing used for each vertical silo. It would appear to be more cost-effective to eliminate these walls by placing the cages in a larger holding tank.

Such a system of three-dimensional silo culture for Homarus has been proposed by researchers at the University of California at Davis (Fig. 8). In this three-dimensional system, the lobsters are held in compartmented trays which were stacked vertically and immersed in large ferrocement silo tanks (Schuur et al., 1974). A movable service gantry is equipped with arms which can lift the tray stack out of the tank, move each of the trays horizontally out of the stack for feeding, and then return the tray to the stack. A full-size functioning prototype of this gantry has been built by scientists in the Agricultural Engineering Department at UCD. This system appears to have considerable potential. However, since the perforated bottom of one tray forms the top of the tray below, it is conceivable that some animals might cling to the top of the container above and be injured or lost when that tray is shifted from one stack to another.

Westinghouse, Inc., has proposed a culture system for Homarus which is a composite of the developments of several research groups (Fig. 9). In this three-dimensional system, the holding trays are arranged in two vertical stacks and are interconnected by means of a chain drive and gear system. The trays are in motion continuously, and are brought to the top of one stack where food is dispersed, and then the tray is moved horizontally to the other stack. Although this design would provide relatively convenient access, several problems may be present in the technology needed to operate complex chain and gear systems in seawater for long periods of time. Also, lobsters may cling to the bottoms of the trays and thereby excape or be injured during the restacking procedure.

Several three-dimensional individual rearing systems have been proposed for the culture of the freshwater prawn (Macrobrachium). Researchers at Trenton State College have developed an inclined tray system (Fig. 10). In this system, a pelletized food is distributed evenly across the surface of a large holding tank. As the pellets sink they are caught on a series of food retention plates. The prawns use their slender chelae to reach through the front mesh on the individual cages and manipulate the food pellets back into the cage. Several functioning prototypes have been constructed and the animals grew and survived well. An economic model of the operation indicated that a reasonable profit margin could be obtained (Stolpe, pers. comm.). One potential problem that needs to be addressed in a method of sequencing the operation of the food distribution device so that the pellets do not fall on the horizontal tops of each tray, where they could not be reached by the prawns.

Two similar systems have been proposed by Syntex, Inc., and Solar Aquafarms Company, both in California. In these systems, all of the cage walls and bottoms are perforated, and food is distributed from above, as in the Trenton design. However, in these systems the food pellets fall directly through the perforated cage bottoms, and are trapped at each level by two different proprietary methods. A general problem with this type of rearing is getting food particles to drop directly and evenly into the animal compartment areas.

The SDSU deep tank system (Fig. 4) appears to be a promising three-dimensional, individual culture system. It offers the relatively low initial costs of other three-dimensional systems, but since the trays are mechanically lifted out daily for feeding and maintenance, a close watch can be maintained for disease, overfeeding, and mortalities. In addition, the concrete raceways in which the vertically oriented trays are suspended can be constructed partially or entirely underground, to reduce both construction costs and problems with building height regulations. Further analyses of these systems should provide the information necessary to assess the commercial feasibility of lobster culture.

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Table 1. Ratings of five methods for the intensive rearing of lobsters, in regard to 11 qualities which are essential to the success of the system.

	CULTURE SYSTEM DESIGN				
	Offshore		Onshore		
				Layered	
	2D	3D	2D	2D	3D
Yield/Bottom Area	low	high	low	medium	high
Control of Environment	low	low	high	high	high
Surface/Volume Ratio	high	medium	high	high	low
Aeration Costs	low	low	medium	medium	high
Water Treatment and Pumping Costs	low	low	medium	high	medium
Land Costs	low	low	high	medium	low
Equipment Costs	low	low	high	medium	low
Ease of Feeding	medium	low	high	medium	medium
Ease of Harvesting	medium	low	high	high	medium
Ease of Monitoring	medium	low	high	medium	low
Potential for Disease Transmission	high	high	medium	low	low

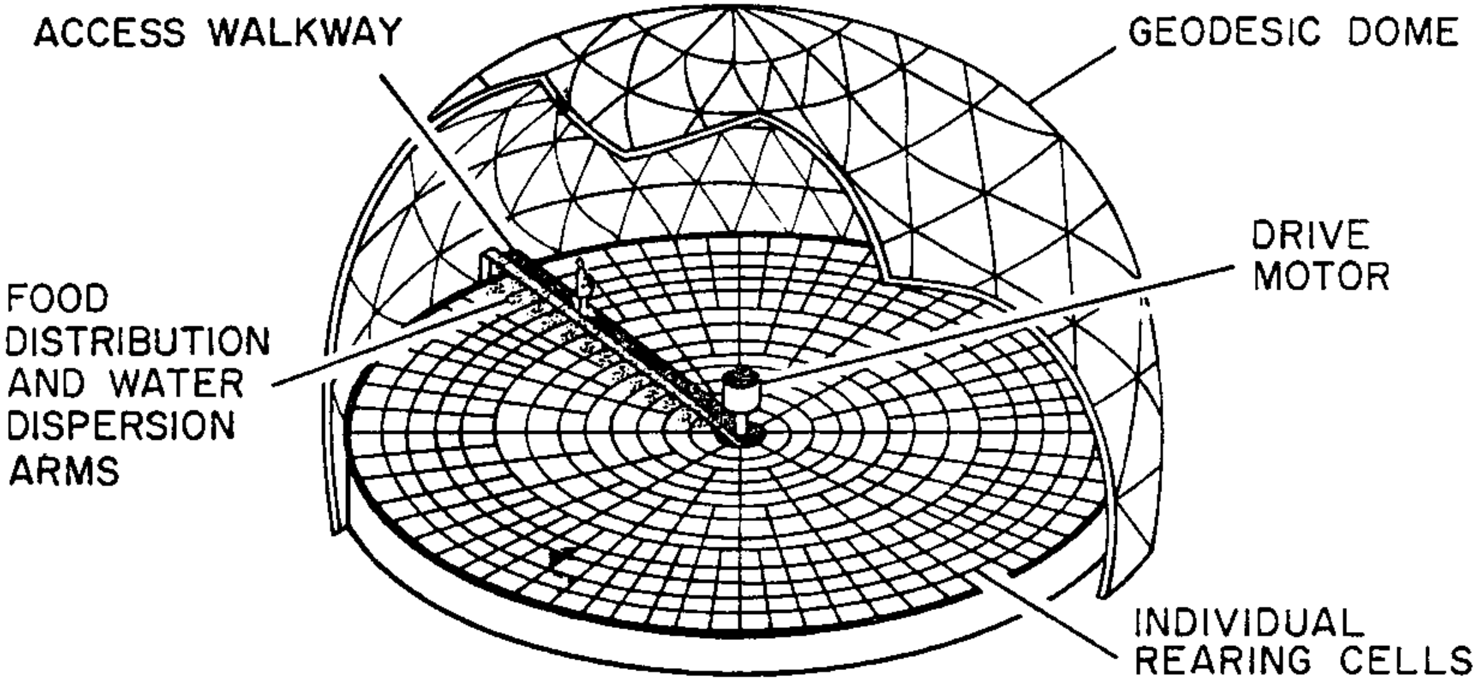

ACCESS WALKWAY
GEODESIC DOME
FOOD DISTRIBUTION AND WATER DISPERSION ARMS
DRIVE MOTOR
INDIVIDUAL REARING CELLS

FIGURE 1.

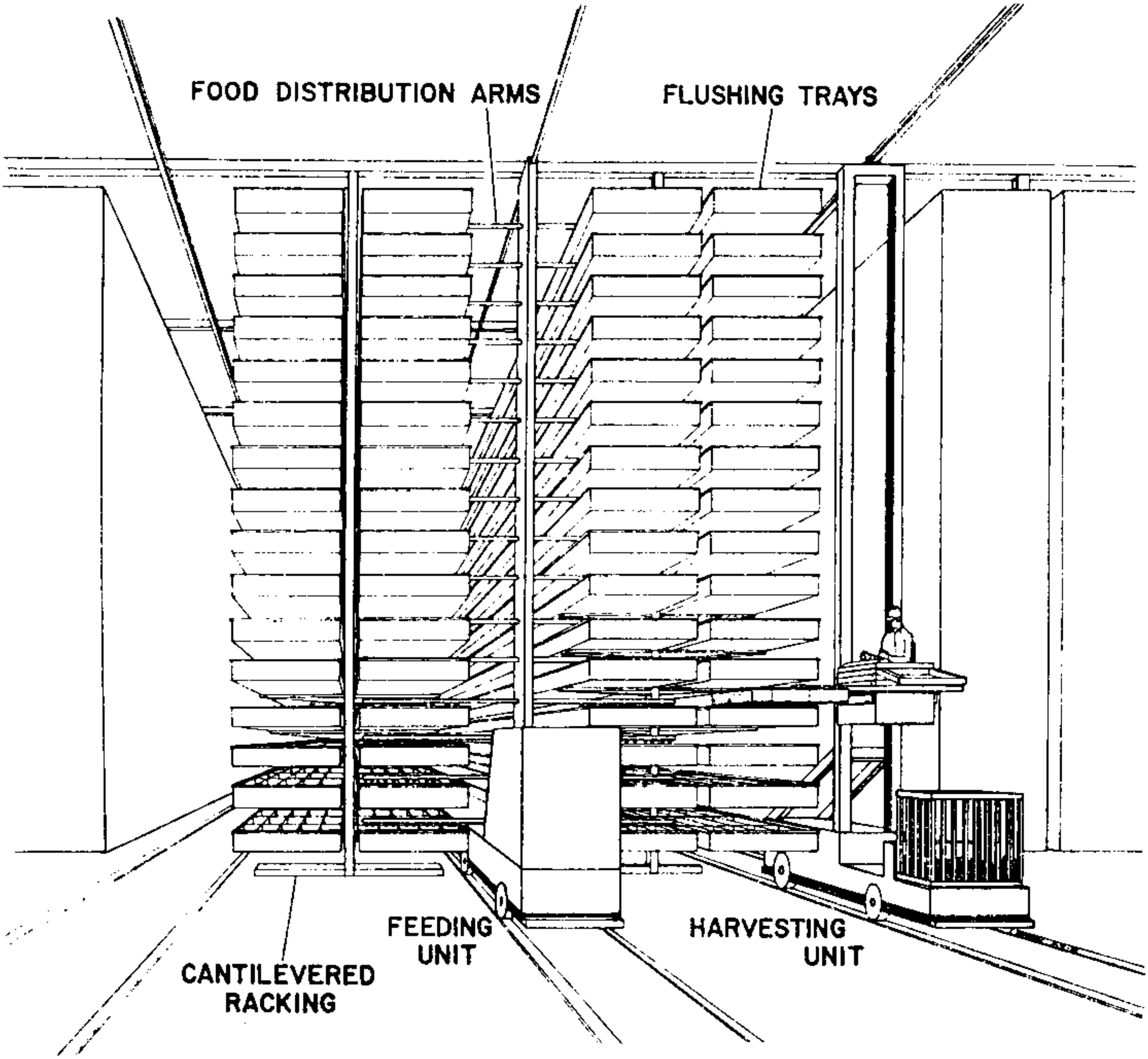
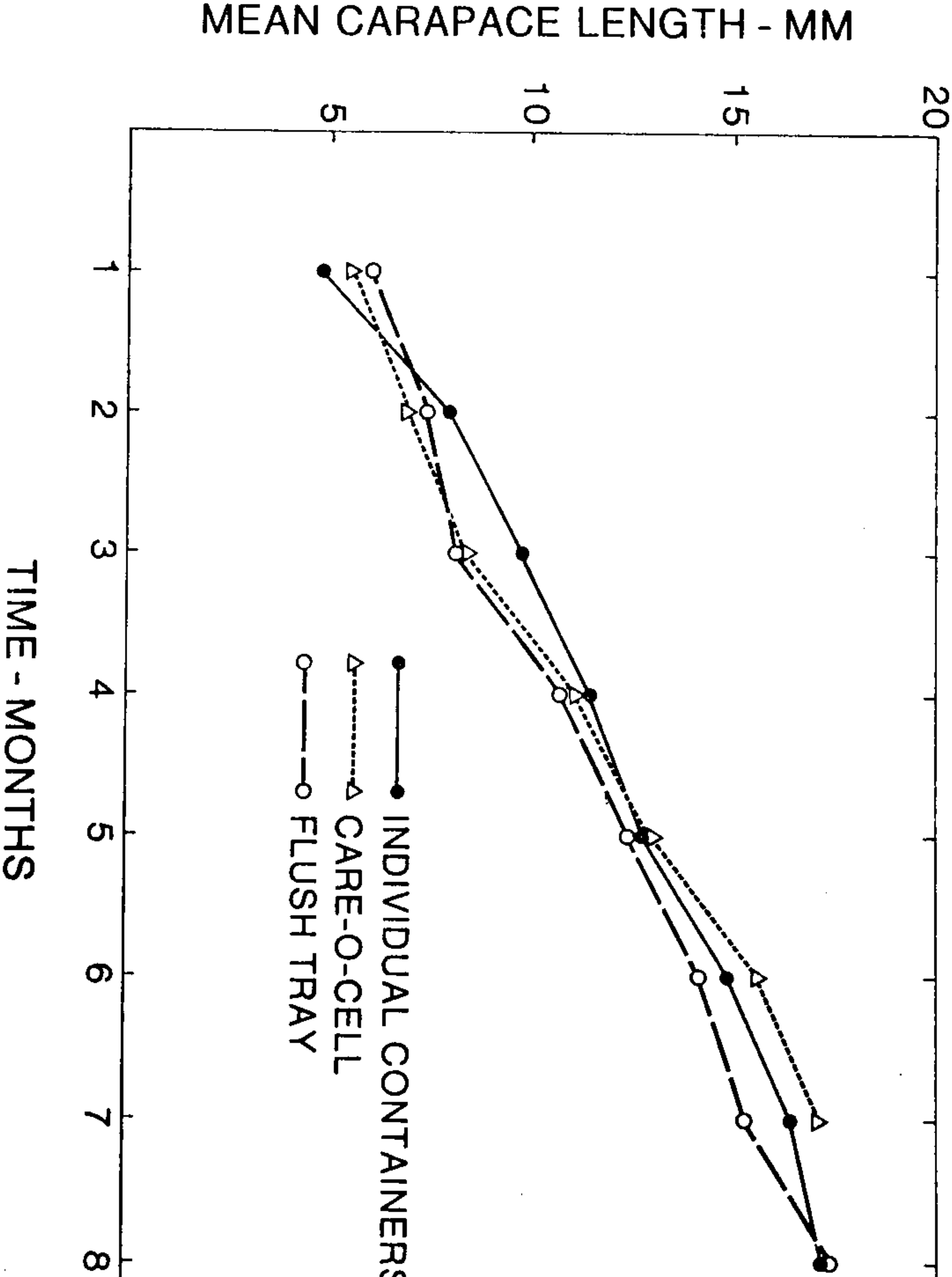

FOOD DISTRIBUTION ARMS
FLUSHING TRAYS
FEEDING UNIT
HARVESTING UNIT
CANTILEVERED RACKING

FIGURE 2.



MEAN CARAPACE LENGTH - MM
20
15
10
5
1
2
3
4
5
6
7
8
TIME - MONTHS
INDIVIDUAL CONTAINERS
CARE-O-CELL
FLUSH TRAY

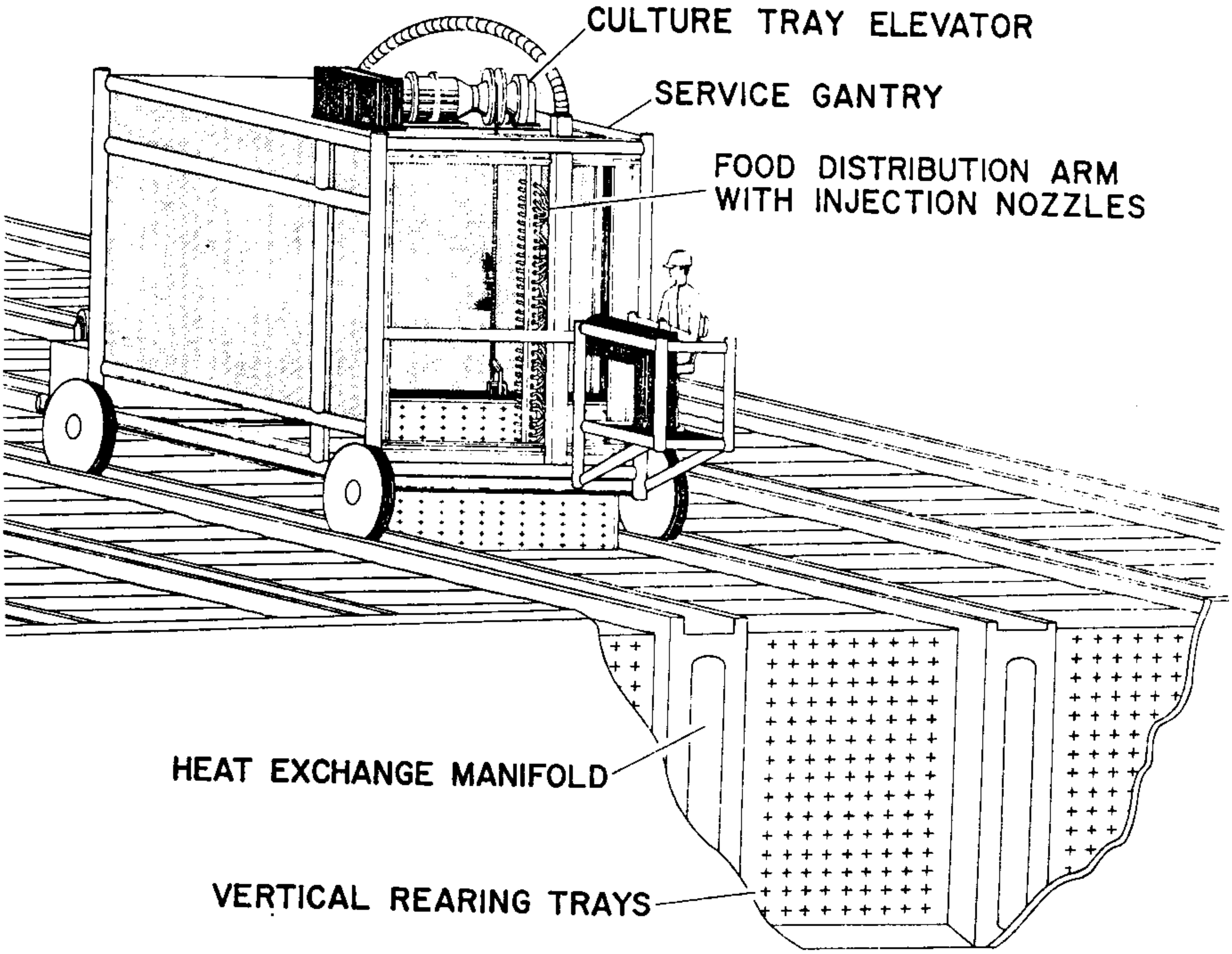

CULTURE TRAY ELEVATOR
SERVICE GANTRY
FOOD DISTRIBUTION ARM WITH INJECTION NOZZLES
HEAT EXCHANGE MANIFOLD
VERTICAL REARING TRAYS

FIGURE 4.

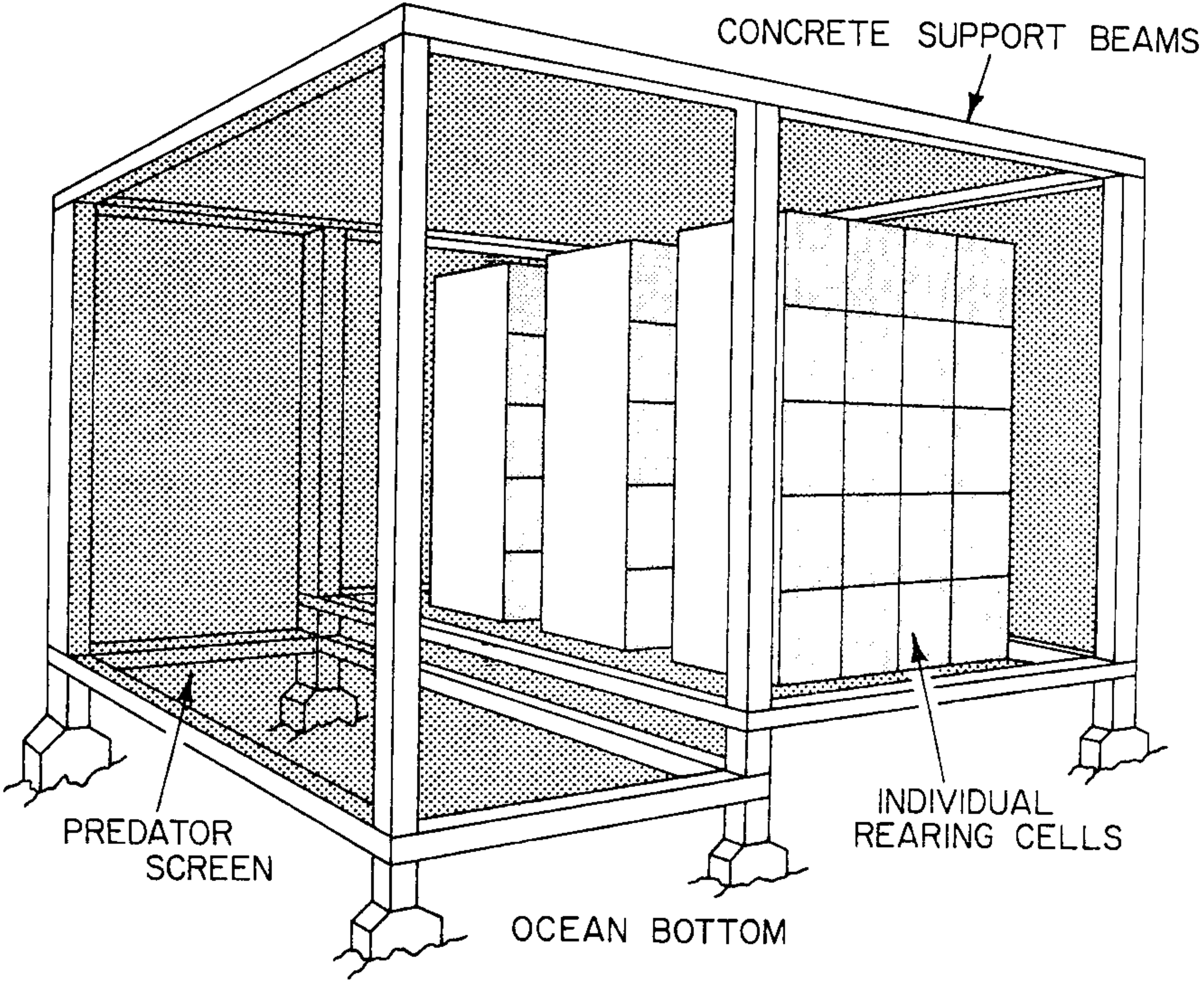
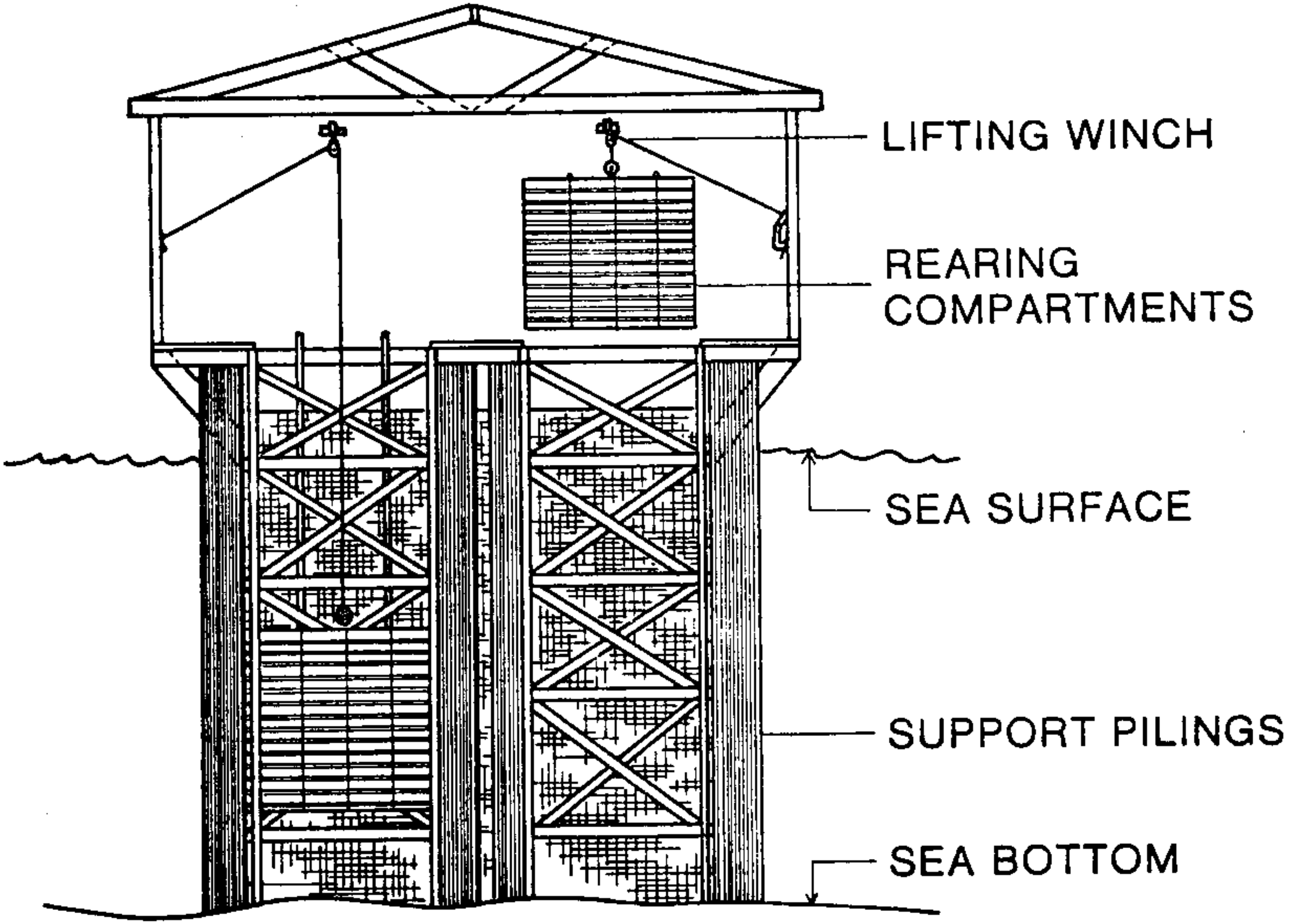
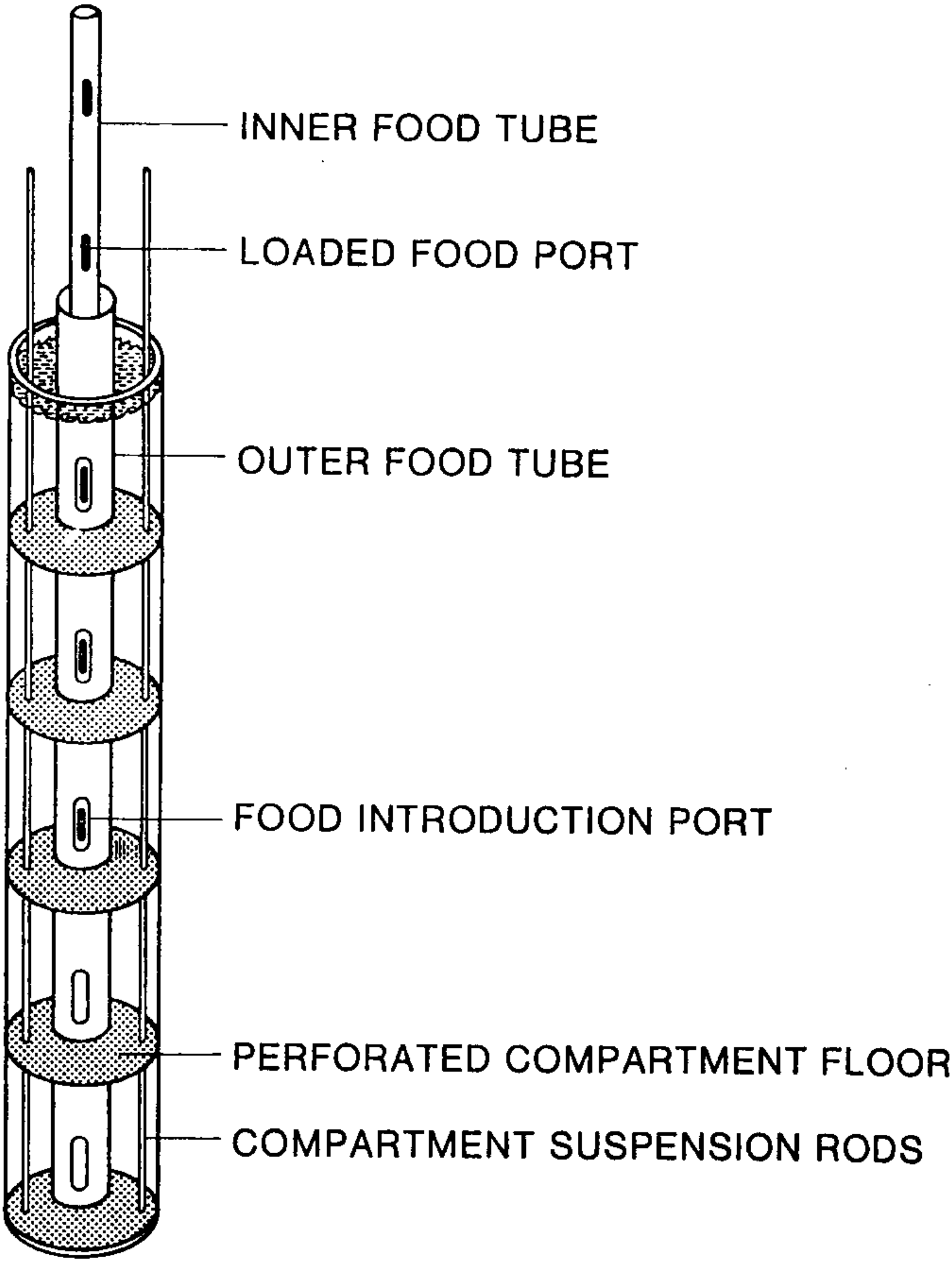

CONCRETE SUPPORT BEAMS
PREDATOR SCREEN
INDIVIDUAL REARING CELLS
OCEAN BOTTOM

FIGURE 5.



OFFSHORE LOBSTER CULTURE PLATFORM

FIGURE 6.



VERTICAL CULTURE TUBE

FIGURE 7.

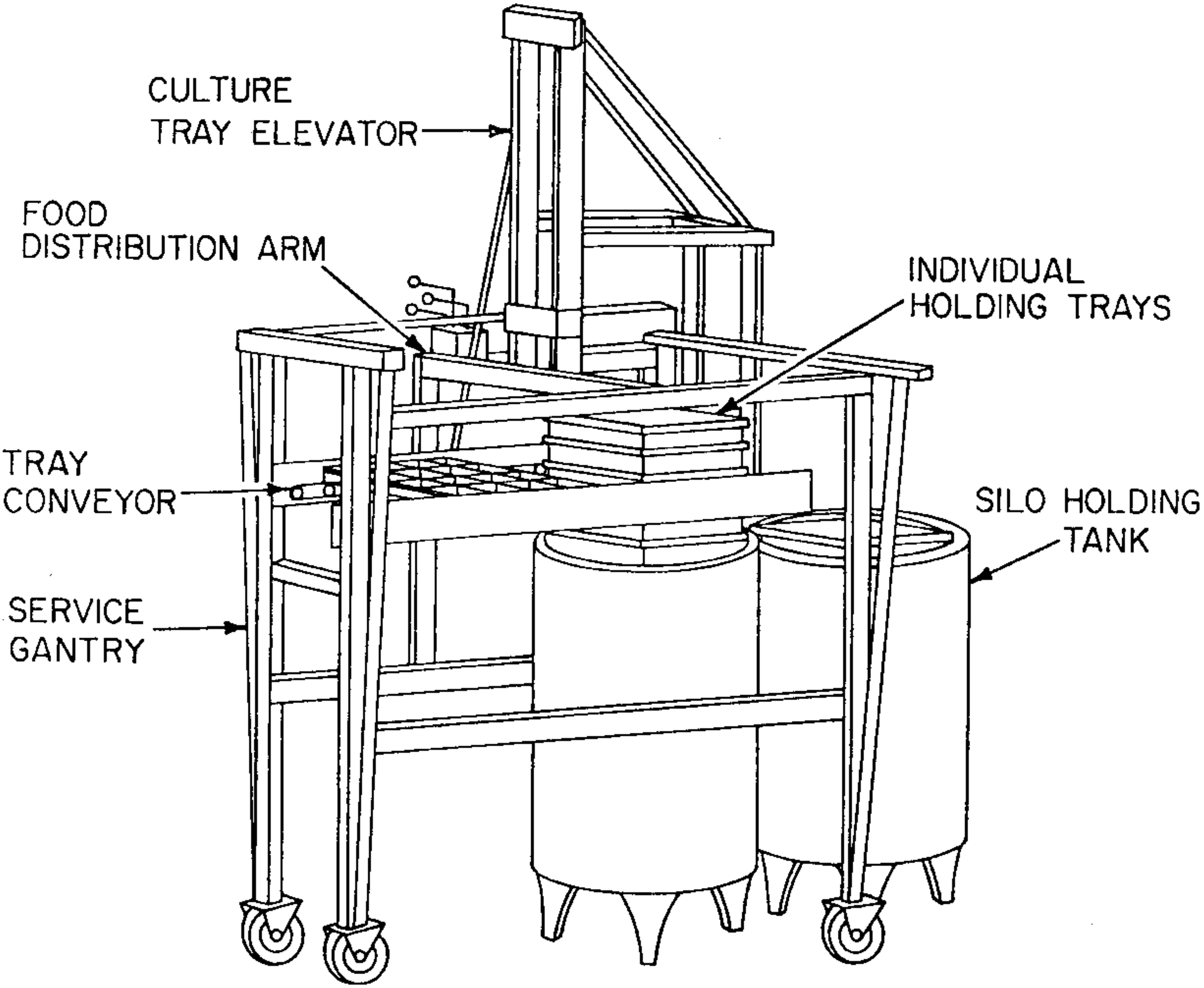
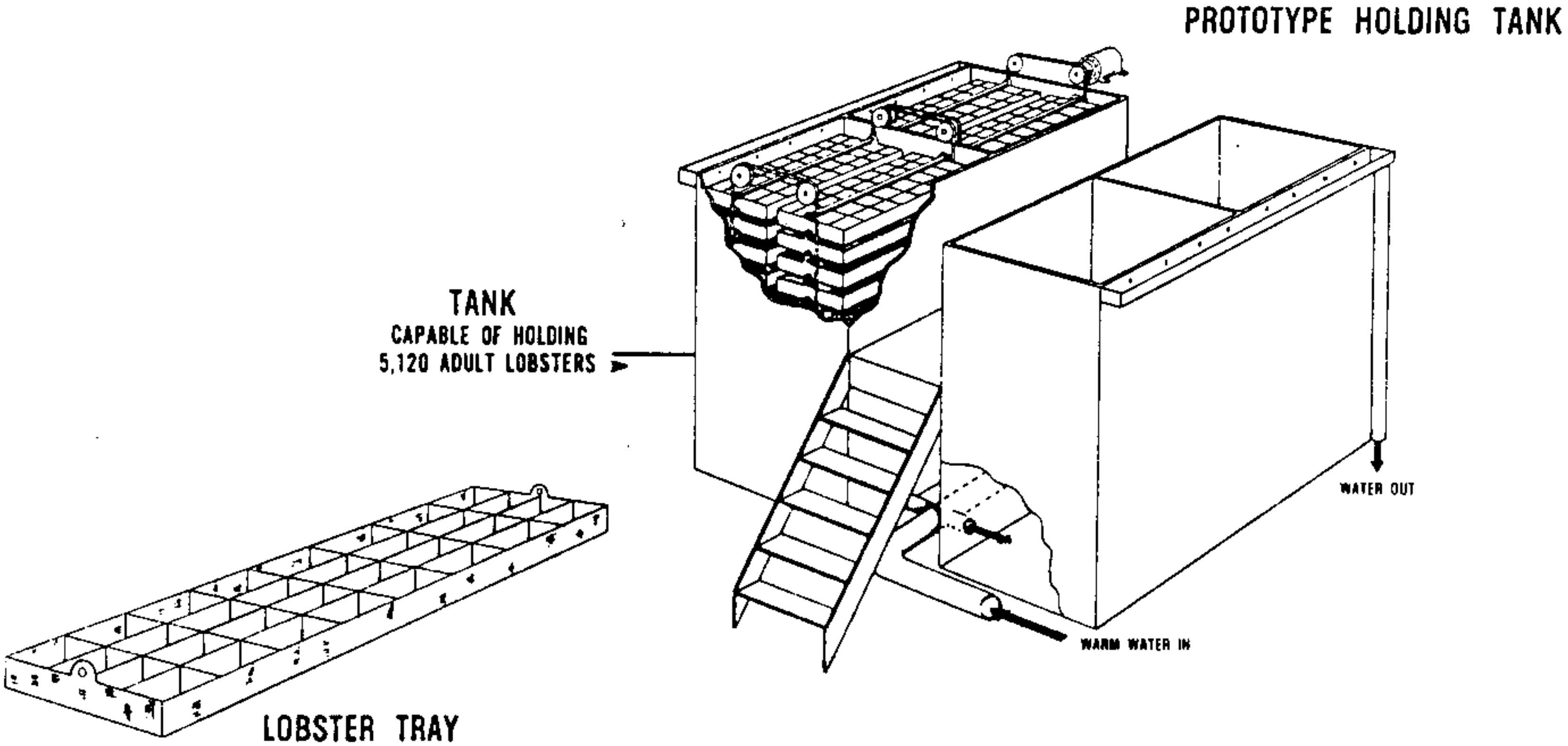
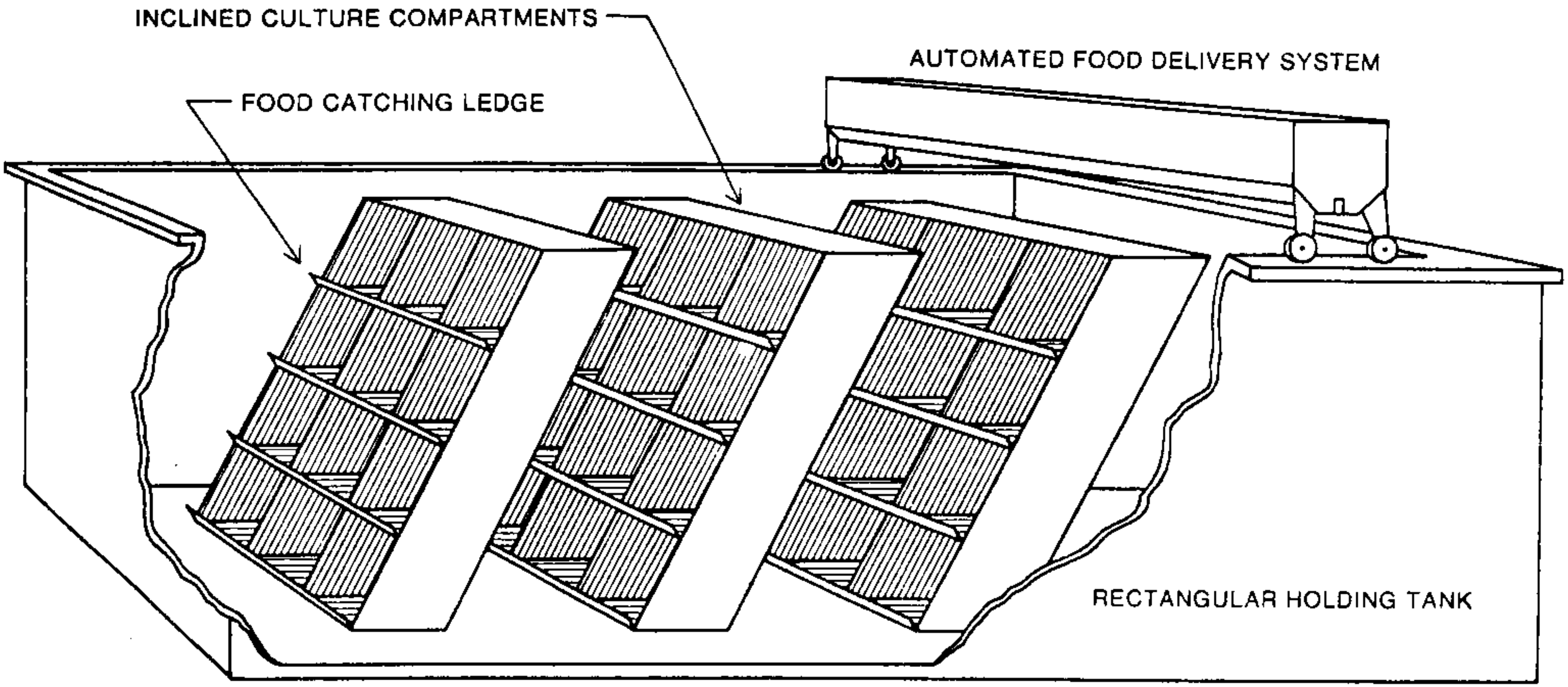

CULTURE
TRAY ELEVATOR
FOOD
DISTRIBUTION ARM
INDIVIDUAL
HOLDING TRAYS
TRAY
CONVEYOR
SILO HOLDING
TANK
SERVICE
GANTRY

FIGURE 8.



PROTOTYPE HOLDING TANK
TANK
CAPABLE OF HOLDING
5,120 ADULT LOBSTERS
WATER OUT
WARM WATER IN
LOBSTER TRAY

FIGURE 9.



INCLINED TRAY SHRIMP CULTURE SYSTEM

FIGURE 10.

LIST OF FIGURES

Figure 1. Conceptual drawing of a rotating care-o-cell lobster culture system. Several prototypes of this system have been constructed and perform satisfactorily.

Figure 2. Conceptual drawing of a flushing tray lobster culture system. Two prototypes of this system have been constructed and perform satisfactorily.

Figure 3. Growth of three groups of lobsters held in a care-o-cell culture system, a flushing tray system, and in solid-bottom individual containers. Regression analysis indicated no significant differences in growth rates of the three groups ($p > .05$).

Figure 4. Deep tank lobster culture system. Artist's conception indicates traveling gantry used for lifting, feeding, and harvesting vertically-oriented culture trays which would be suspended in long concrete raceways. A prototype of this system is currently being evaluated.

Figure 5. Offshore three-dimensional lobster culture system proposed by a commercial group in 1972. Lobster traps would be fed and maintained by divers.

Figure 6. Offshore three-dimensional lobster culture system proposed and patented in 1968. Lobster trays would be lifted to the surface for feeding and maintenance.

Figure 7. Vertical tube lobster culture system. A pilot-scale farming operation employing several sizes of vertical acrylic tubes is currently underway.

Figure 8. Silo tank lobster culture system. A full-scale functioning prototype of the ferrocement tanks and the traveling service gantry has been constructed and evaluated.

Figure 9. Moving tray lobster culture system proposed by a commercial group in 1975. The design is a composite of ideas developed at several research institutions.

Figure 10. Inclined tray shrimp culture system. Prototype trays of several sizes have been constructed and evaluated.