DEVELOPMENT OF HIGH DENSITY CULTURE TECHNIQUES FOR LOBSTERS AND OTHER CRUSTACEANS

James M. Carlberg and Jon C. Van Olst
San Diego State University
San Diego, California

Abstract. The objectives of this research program are to evaluate the usefulness of waste heat from steam electric generating stations as an inexpensive and suitable source of warmed seawater for use in aquaculture of American lobsters and to develop the techniques and systems necessary for the commercially viable culture of this species. Growth rates of larval and juvenile stage lobsters are significantly greater in effluent of elevated temperature than at ambient ocean temperature, while survival is essentially the same in water of effluent and ocean quality. Water quality analyses suggest that concentrations of heavy metals and chlorinated hydrocarbons are similar in each water source. These concentrations are at least an order of magnitude below the median lethal limits determined in acute toxicity studies.

Related research on the potential of controlled reproduction and hybridization, as well as the communal rearing of larval and early juvenile stages is discussed. The present status of nutrition research and programs for disease prevention are described. Prototype production modules for the individual rearing of juvenile lobsters to market size are presented. The cost effectiveness and relation of each component to total production cost are considered. Latest cost projections indicate that lobster culture utilizing these systems may be economically feasible. This technology may be applicable in the intensive culture of other cannibalistic crustaceans.

INTRODUCTION

Efforts to develop techniques for the culture of lobsters in controlled environmental systems have concentrated on the homarid species, primarily the American lobster (Homarus americanus) and the European lobster (Homarus gammarus). The palinurid or spiny lobsters have a worldwide distribution, but have received less attention because of their specialized environmental requirements and long pelagic larval development. A period of eleven to fourteen months is required for the pelagic phyllosoma larval stage at sea. Projected growth rates suggest that this developmental period may be reduced to less than five months in the laboratory if reared at elevated temperature, and if satisfactory food is provided (Dexter, 1972). Although the palinurids have yet to be successfully reared through their entire pelagic larval stages, because of their gregarious habits and low incidence of cannibalism, they have the potential for extensive pond rearing, similar to the techniques presently utilized in the commercial culture of marine and freshwater shrimp.

The American lobster (H. americanus) has been identified as one of the priority species for commercial cultivation in the United States (Black, 1973). There is considerable justification for selecting this species as a candidate with vast aquaculture potential. The American lobster is characterized as having a broad physiological tolerance, is capable of accelerated growth, reproduces in captivity, has an abbreviated larval development, is moderately disease resistant, and demands a high market price.

Research conducted in the aquaculture program at San Diego State University has concentrated on the use of thermal effluent from steam electric generating stations in the culture of the American lobster and on the development of techniques for the commercial culture of this species.

The research is being conducted at two power plant laboratories, the Redondo Beach Generating Station of the Southern California Edison Company and the Encina Power Plant of the San Diego Gas & Electric Company. Other related experiments are conducted in the SDSU aquaculture laboratory at the Scripps Institution.

This research concerns the biological and technological problems which must be solved before commercially viable lobster culture will be possible. A very large amount of relevant information is now available. Major accomplishments include: 1) the development of satisfactory systems for larval culture; 2) the development of automatic feeding systems; 3) information on feeding requirements, activity patterns, and social behavior of the American lobster; 4) the development of techniques for mass rearing of juveniles; 5) information on optimal feeding rates for larvae and early juveniles; 6) information on optimal temperatures for lobster culture; 7) detailed evaluations concerning the use of thermal effluent in lobster culture; 8) information on the diagnosis, treatment and prevention of diseases; 9) the development of methods for analysis of cost-effectiveness; 10) the development of several promising artificial diets; and 11) the development of new rearing systems for use in the commercial culture of juvenile lobsters to a marketable size.

Research at the Redondo Beach laboratory and some aspects of research at the Scripps Institution laboratory were sponsored by the Research and Development Program of the Southern California Edison Company under contract U2585907. Additional support for the research at the Scripps laboratory and at the Encina laboratory was provided by the NOAA Office of Sea Grant, Department of Commerce, under grant NOAA 04-6-158-44021. The U.S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright notation that may appear herein. Contribution No. 00 from the San Diego State University Center for Marine Studies.

RESULTS

Water Quality

One major aspect of our research has been to conduct comparative water quality analyses, lobster tissue analyses, acute toxicity studies, and rearing experiments to assess the benefits and problems in using thermal effluent to culture the American lobster from the egg to market size. Atomic absorption analysis of intake and effluent water samples from three fossil-fuel generating stations indicated that the condenser cooling systems apparently did not affect the concentrations of Cu, Zn, Cd, Co, Cr, Pb, and As in the

Table 1. Estimated lobster production costs with and without the use of thermal effluent as a source of heat. (Data from W. Johnston, University of California, Davis.)

	Production Costs Using Ambient Temperature Seawater Heated from 12 C to 21 C		Production Costs Using Steam Electric Generating Station Thermal Effluent Seawater (21 C)	
	$ per unit output	% of total cost	$ per unit output	% of total cost
Space	0.68	13	0.68	30
Heat	2.90	56	0.00	0
Pumping	0.06	1	0.06	3
Waste Treatment	0.08	2	0.08	4
Aeration	0.05	1	0.05	2
Food	0.96	19	0.96	43
Labor	0.37	7	0.37	16
Larval	0.04	1	0.04	2
TOTAL COST:	$ 5.14		$ 2.24	

ASSUMPTIONS:

Months to output. 30.0
Plant output (thousand/month) 80.0
Harvest Weight (grams/animal) 502.6
Total capital ($100,000). 31.05
Culture capital. . . . . (25.22)
Waste treatment capital. . . . .(5.83)
Tank are (1000 m^2). 98.95
Water reuse (% recirculation) 0.00
Intake flow (million liters/day). 43.45
Land area for production facility (hectares). . 2.75
Conversion ratio. 3.30

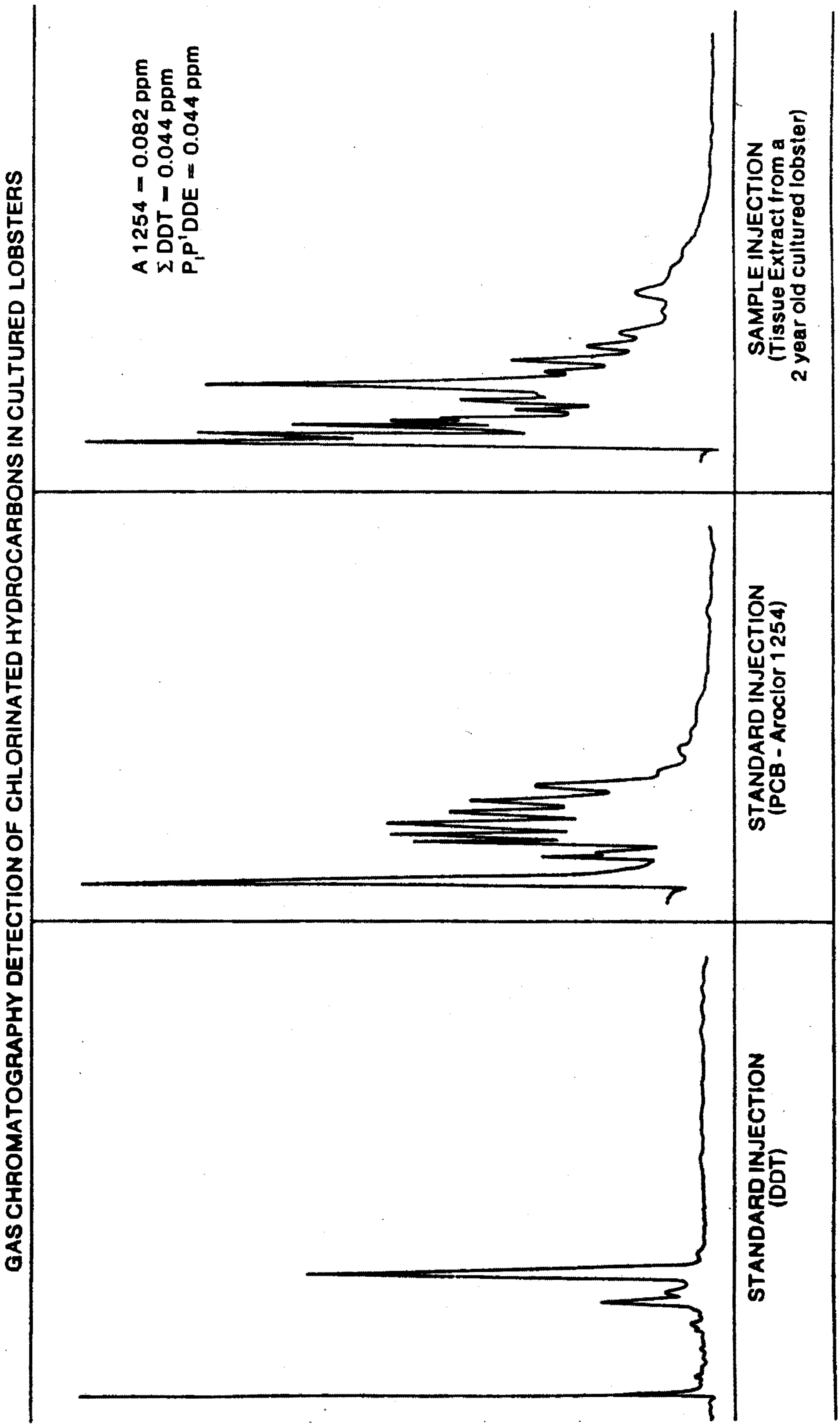

Fig. 1. Gas chromatography curves used to identify chlorinated hydrocarbon compounds found in the tissues of cultured lobsters.

thermal effluent or the intake seawater. The concentrations of these heavy metals in all tissues were well below Food and Drug Administration (FDA) limits for these metals in foodstuffs. Lethal limits for these seven metals, as determined by bioassay experiments, were all at least an order of magnitude higher than levels of the chemicals encountered in generating station effluents. Growth and survival of larval and juvenile lobsters maintained in long-term rearing experiments at constant temperatures were not significantly different in effluent, intake, and Scripps water sources (Ford et al., 1975; Dorband et al., 1976). These results indicate that the thermal effluent from typical fossil fuel generating stations in southern California provides a suitable heated water source for the culture of American lobsters.

Another aspect of water quality research involves measurement of the chlorinated hydrocarbon compounds, such as DDT, and PCB's, which may be present in seawater at levels high enough to accumulate in lobster tissues and make the animals unsuitable for human consumption. Certain of these chemicals, such as vinylchlorides and plasticizers, may be introduced into the seawater as they are leached from components used in the culture systems.

Samples of seawater from SIO, and intake and discharge water from the power station sites were surveyed for chlorinated hydrocarbons. Preliminary results indicated that several compounds were present in the seawater, but at levels low enough so that growth and survivorship of the animals would not be impaired. Some of the compounds found in the seawater were the pesticides DDT, lindane and dieldrin, and the plasticizer Aroclor 1254. In no case did it appear that the power plants were influencing the levels of contaminants in the water, since measurements of intake and discharge water were essentially equal. Preliminary measurements of the levels of hydrocarbons which have accumulated in the edible tissue of lobsters cultured for approximately two years at our SIO laboratory are shown in Figure 1. Pesticides and plasticizers were also found, but at very low levels. Continued research will establish acute lethal limits (LD_{50}'s) and chronic effects for artificially induced levels of those chlorinated hydrocarbons which are found to be present in potentially toxic concentrations. These will include DDT, Aroclor 1254, and vinylchloride. It is necessary to know what levels of these pollutants would be limiting to growth and survivorship so that recommendations can be made regarding the suitability of various areas for aquaculture, and so that results will have widespread applicability.

A second major area of water quality research involves toxicants which are produced by the cultured animals themselves. Ammonia is the primary excretory product of lobsters and is known to be highly toxic to *H. americanus*. Because of this, specific knowledge of tolerances to this compound is essential for proper design of semiclosed culture systems used in rearing species at high densities.

In a series of experiments, threshold concentration and incipient 50% lethal concentration (LC_{50}) were determined for Stage IV larval lobsters (Figure 2). Toxicity appeared to be related to the un-ionized NH_3 fraction. This fraction is dependent upon the effects of pH, temperature, and salinity on the NH_3/NH_4^+ equilibrium. Increasing pH caused markedly higher mortalities. Evidence concerning possible effects of both temperature and salinity on ammonia toxicity was less clear (Delistraty et al., 1977). From these data a "safe" ammonia tolerance level was determined.

A simplified steady-state model was developed for predicting optimum carrying capacity in culture systems for juvenile and adult lobsters, as a function of degree of water reuse, ammonia removal efficiency, water flow rate, ammonia excretion rate, and ammonia concentration of the ambient source intake water.

Effects of Elevated Temperature

Previous research has established that the optimal temperature for culturing H. americanus is 21-22 C. We have also demonstrated thermal effluent to be an inexpensive source of warmed seawater for culturing lobsters and other species with high physiological temperature tolerances in temperate geographical zones. As a logical and important extension of this work experiments are now in progress to assess the influence of fluctuating temperatures on growth and survival.

Constant temperatures are rarely encountered either in the natural or aquaculture environments. We have observed that sudden temperature changes will often induce molting. Lobsters were subjected to several different temperature extremes for varying lengths of time. Some influence of cold temperature shock on molting was evident and was not detrimental until the thermal limits were approached. It has been suggested that a cold period promotes the physiological events leading to molting, and therefore may result in increased growth rates. Cyclic temperature regimes may be useful in the staging and synchrony of molting, reproduction, and embryonic development. An applied thermal stimulus at the appropriate time in the molt cycle may accelerate molting and therefore growth. Subjecting juveniles in communal rearing systems to a periodic cold treatment might reduce cannibalism significantly if most animals were in soft post-molt condition simultaneously.

Reproduction and Hybridization

In the past lobster researchers have depended upon a source of egg-bearing females captured from the wild. However, in recent years many accomplishments have been made in the development of techniques for successful year-round reproduction in captivity. Homarid lobsters are generally quite promiscuous and mate immediately following molting of the female. Extrusion of eggs occurs in three to four months when development is accelerated at elevated temperatures of 22 C. In most cases, hatching occurs within four months after extrusion and a second reproductive cycle can be initiated after only two months elapse. Unfortunately, many females expel their eggs prematurely and the abortifacient cause is currently being investigated.

We have successfully crossed the American lobster, H. americanus, with a closely related European species, H. gammarus. Accurate prediction of egg development and hatching was accomplished with a slight modification of the Perkin's Index. Following successful hatching of the hybrid larvae last spring, comparative growth experiments were initiated. Previous comparisons revealed that both species have nearly identical rates of growth (Van Olst et al., 1976). Preliminary results after seven months of growth indicate that the hybrid progeny exhibit growth rates superior to the parent stock.

Disease

The American lobster is known to be moderately disease resistant. Red tail or Gaffkemia, which is the major cause of disease among wild populations, has not proved to be a problem in the culture of lobsters. However, there are infrequent infestations by other bacteria in the larval and early juvenile stages. The most common pathogen affecting the larval stages is Leucothrix mucor which can be successfully controlled by administering appropriate antibiotic agents. Rare occurrence of other filamentous and chitinolytic bacteria and a few phycomycetous fungi have been reported (Fisher et al., 1975). Research is in progress on the development of prophylactic and treatment procedures and some results indicate the potential for immunization against some of these bacterial diseases (Schapiro and Steenbergen, 1974).

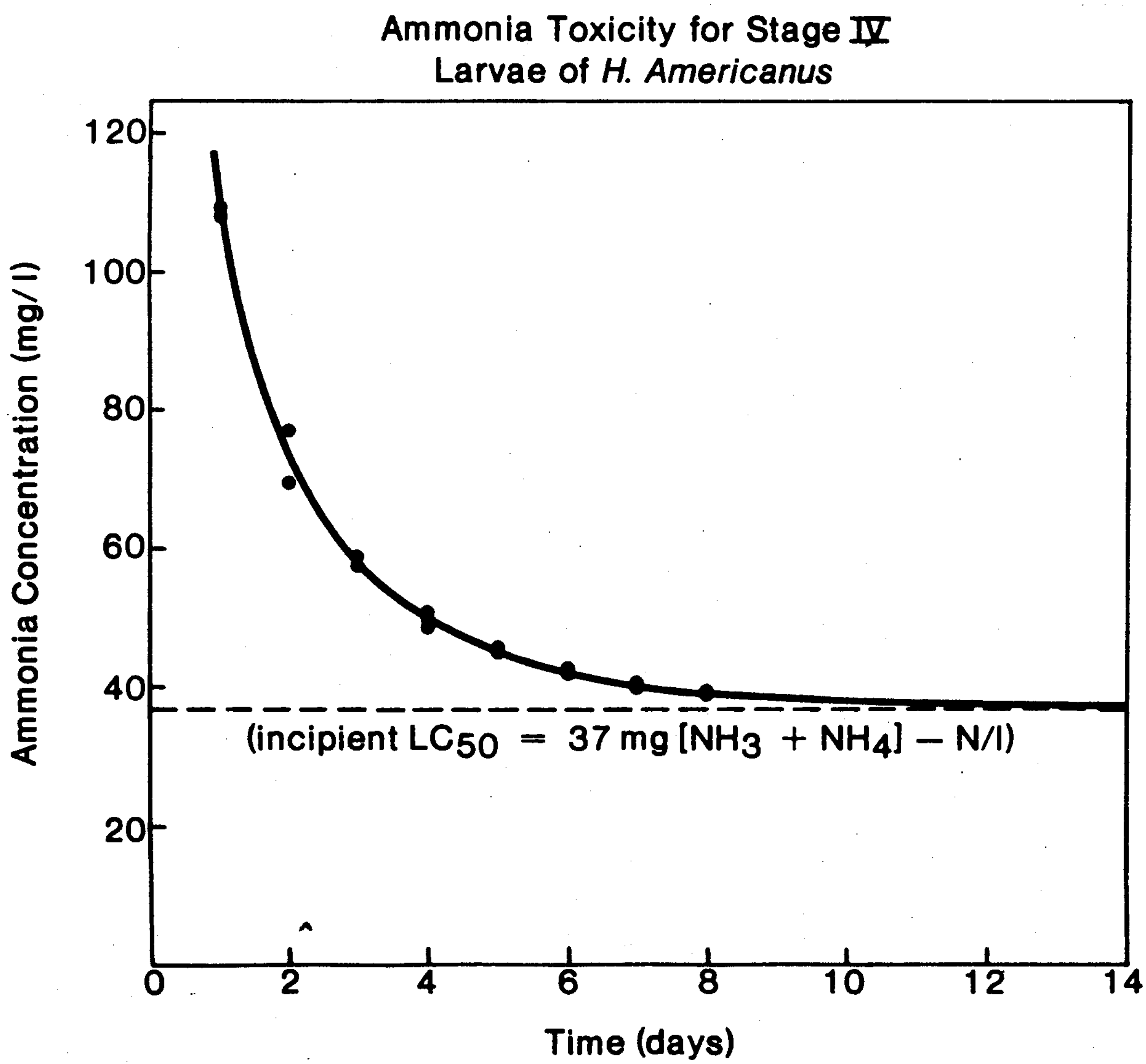

Fig. 2. Graph illustrates the concentrations of ammonia which result in 50% mortality of larval lobsters after exposure to this toxicant for varying lengths of time.

Development of Artificial Diets

Several experimental shrimp diets were shown to be nutritionally deficient or imbalanced for lobsters. These rations, when supplemented with pelagic red crab, Pleuroncodes planipes, produced growth rates similar to those achieved for lobsters fed frozen brine shrimp (Van Olst et al., 1975). Ingredient analysis has shown that pelagic red crab has a broad amino acid spectrum, and is high in lipid content and essential carotenoids. In recent feeding trials it was determined that a 10-20 percent addition of crab meal was sufficient to accomplish this accelerated growth. This level is nearly identical to the concentration determined by fish nutritionists to be necessary for salmonids. These results further demonstrate the value of pelagic red crab meal as aquaculture feed ingredient. The supplemented feed can now be used as a temporary maintenance diet which is less expensive to produce and more conveniently stored and delivered to individual rearing compartments. However, while this diet is superior to other manufactured feeds tested, it is still nutritionally deficient when compared to a live brine shrimp control diet.

Current nutrition research is designed to assess the interaction of the five major dietary components: proteins, saturated and unsaturated fatty acids, vitamins, and carotenoid precursors. This is a cooperative research project by three groups within the UC Sea Grant Program involving diet formulation at the Bodega Marine Laboratory, analysis at Foremost Research Center, and evaluation at the SDSU aquaculture laboratory.

Communal Rearing of Juvenile Lobsters

Communal rearing may have potential for the production of early juvenile stages, since these systems are less complex and are less expensive to operate than individual rearing systems. However, several experiments have resulted in low survival and yielded individuals of non-uniform size. For example, during six months of communal rearing, dominant individuals achieved a carapace length as large as 44 mm, while their subordinates grew from the same initial size of 5 mm to only 10 mm in length.

We have identified the major factors controlling the establishment of dominance orders and the degree to which these factors influence cannibalism (Van Olst et al., 1975). Experiments recently completed to further optimize environmental culture conditions indicate that three-dimensional use of the water column incorporating vertical substrates may be essential in an economical communal rearing program.

Other results show that a stocking density of 100 individuals per sq. meter will yield juveniles of 20 mm carapace length with 40% survival after six months of culture. Attempts to determine the influence of photoperiod on the nocturnal feeding patterns described in earlier reports indicate that constant dark produces lower survival in communal rearing systems, and that a light cycle between 18 and 24 hours is optimal.

Culture System Development

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. Several production systems for intensive individual culture have been designed. Working models of three culture systems showing considerable potential were constructed and their performance characteristics are being compared. One system consists of a fiberglass tray from which the water is flushed periodically to remove wastes from lobster holding cells constructed of perforated plastic. A prototype of this unit with rearing compartments to hold 1,000 lobsters individually has been constructed and dye studies of its flow and flushing characteristics completed. The rapid flow resulting from periodic flushing has a scouring effect on the bottom screening and on

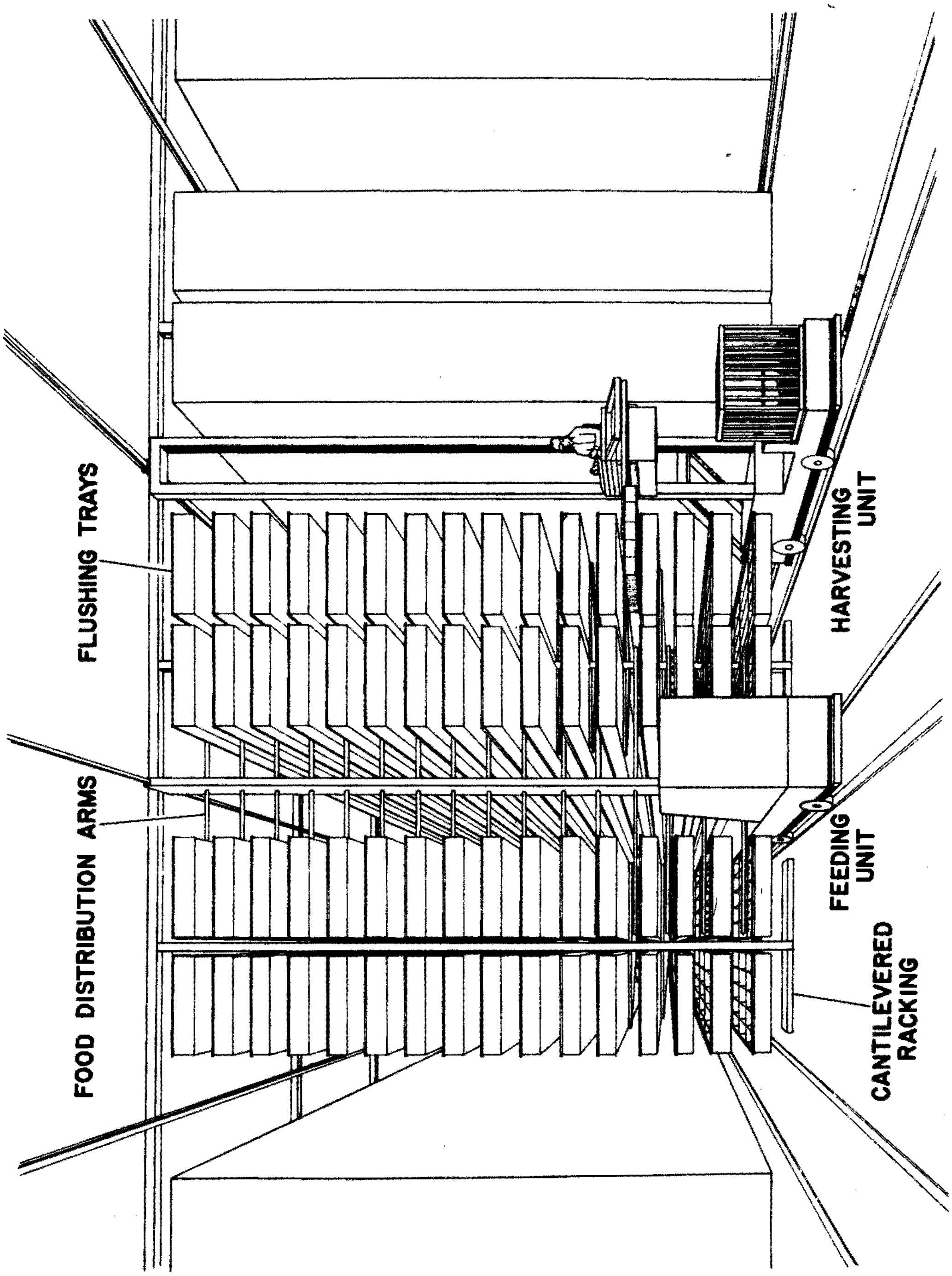

Fig. 3. Artist's conception of full-scale version of the cantilevered tray system, incorporating semi-automated machinery for feeding and harvesting.

the bottom of the tray, so that the entire system is almost completely self-cleaning. The flushing tray appears to be outstanding in its ability to hold large numbers of animals in a minimal amount of space, deliver oxygenated seawater evenly to each compartment, and remove wastes rapidly and economically. A cooperative effort with the University of Colorado's Department of Architecture is underway to design a full-scale version of this system (Figure 3).

The cantilevered tray system requires minimal space by supporting 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 tray system consists of a large, deep holding tank in which perforated rearing container units are hung vertically and are lifted out by an overhead winch or gantry for stocking, feeding, and harvesting (Van Olst et al., 1977). Further evaluation of these and other systems is necessary before larger than laboratory scale production should be attempted.

The space requirements for lobsters under intensive culture conditions represent an important economic consideration in growing the juveniles to market size. We are conducting long-term experiments to determine the minimum space required for rapid growth of lobsters of different life stages in individual rectangular compartments. Results after one year of culture suggest that for optimum growth the container width should be greater than the total body length of the lobster (Figure 4). It is possible that some reduction in growth rate may be tolerable if sufficient savings are realized in the costs of constructing the smaller facility which would be required if smaller culture containers were employed.

Economics

We have designed and conducted our research program in close cooperation with the cost modeling group at University of California, Davis. The results of the confinement, ammonia tolerance and communal rearing experiments have been incorporated into the model (Botsford, 1977). In addition, progress has been made toward the development of a return-on-investment (ROI) analysis, which will be of more direct use to the emerging aquaculture industry. ROI computations are the standard methods which venture capitalists utilize to assess the economic feasibility of a new business.

More information has been obtained to indicate that the use of thermal effluent in aquaculture should result in significant production cost reductions. Table 1 illustrates the potential savings in production costs if thermal effluent were used as a cost-free source of heat. In areas where ambient seawater temperatures are about 12 C, production costs are decreased by more than 56% (Allen and Johnson, 1976). These computations stress the potential benefits to be derived from the use of thermal effluent in aquaculture.

Other Species

The technology developed for the intensive culture of lobsters is complex when compared to traditional methods for rearing less cannibalistic species in ponds. Nevertheless, these techniques are valuable in the solution to problems encountered in the high density culture of other cannibalistic crustaceans. One similar crustacean with considerable aquaculture potential is the Malaysian prawn, Macrobrachium rosenbergii. Although this species is less cannibalistic than the American lobster and can be pond reared, projections suggest that yields may be increased ten to one hundred times if reared intensively (Goodwin and Hanson, 1974). Another cannibalistic crustacean of high commercial value is the Mangrove crab, Scylla serrata. This species has considerable potential for aquaculture, provided that yields can be increased through methods which reduce agonistic encounters which lead to cannibalism. The marine shrimp, Penaeus species, although traditionally reared in ponds, have been shown to produce greater yields when intensively cultured in raceways (Goodwin, 1975).

Thermal Effluent Aquaculture

Recycling of food processing and industrial wastes, including thermal effluent, in aquaculture was one of the key recommendations resulting from the United Nations/Food and Agriculture Organization Technical Conference on Aquaculture, held in Kyoto, Japan in May 1976. The use of thermal effluent from steam electric generating stations eliminates many of the site related problems which currently restrain the development of mariculture in developed countries located in temperate zones. Coastal generating stations have the available land and provide a source of warm seawater. However, success depends on exercising appropriate caution in selecting a site. Site selection should be based on water quality, compatibility with scale and fouling prevention procedures, and on constant and sufficient temperature elevation (Muench, 1976). Thermal effluent aquaculture utilizes a waste energy resource, may partially compensate for any adverse ecological effects of thermal discharge, and contributes to economically viable production of foodstuffs. Several existing power plants have altered operations to accommodate aquaculture, and some new plants are incorporating aquaculture as an alternative component in cooling system design criteria.

LITERATURE CITED

Allen, P. G., and W. E. Johnson. 1976. Research direction and economic feasibility: an example of systems analysis for lobster aquaculture. Aquaculture 9(2):155-180.

Black, C. A. (ed.). 1973. Summary Report to Participants, NOAA Aquaculture Workshops, 1972. Publ. by Mardela Corp., Burlingame, California.

Botsford, L.W. 1977. Current economic status of lobster culture research. Proc. World Mariculture Soc. Eighth Ann. Meeting (in press).

Delistraty, D. A., J. M. Carlberg, J. C. Van Olst, and R. F. Ford. 1977. Ammonia toxicity in cultured larvae of the American lobster, Homarus americanus. Proc. World Mariculture Soc. Eighth Ann. Meeting (in press).

Dexter, D. M. 1972. Molting and growth in laboratory reared phyllosomes of the California spiny lobster, Panulirus interruptus. Calif. Fish Game 58(2):107-115.

Dorband, W. R., J. C. Van Olst, J. M. Carlberg, and R. F. Ford. 1976. Effects of chemicals in thermal effluent on Homarus americanus maintained in aquaculture systems. Proc. World Mariculture Soc. Seventh Ann. Meeting (in press).

Fisher, W. S., E. H. Nilson, and R. A. Shleser. 1975. Diagnostic procedures for disease found in egg, larval, and juvenile cultured American lobsters. Proc. World Mariculture Soc. Sixth Ann. Meeting. Pp. 323-333.

Ford, R. F., J. C. Van Olst, J. M. Carlberg, W. R. Dorband, and R. L. Johnson. 1975. Beneficial use of thermal effluent in lobster culture. Proc. World Mariculture Soc. Sixth Ann. Meeting. Pp. 509-515.

Goodwin, H. L., and J. A. Hanson. 1974. The Aquaculture of Freshwater Prawns (Macrobrachium species). Workshop on the Culture of Freshwater Prawns. Publ. by The Oceanic Institute, Waimanalo, Hawaii. 95 p.

_______________ (ed.). 1975. Workshop on the Culture of Penaeid Shrimp, held October 8-11, 1975, Galveston, Texas. Publ. by The Oceanic Institute, Waimanalo, Hawaii (in press).

Muench, K. A. 1976. The role of the electric utilities industry in developing the use of thermal effluent in aquaculture. Proc. World Mariculture Soc. Seventh Ann. Meeting (in press).

Schapiro, H. C., and J. F. Steenbergen. 1974. Active immunity to Gaffkemia in lobsters. Proc. World Mariculture Soc. Fifth Ann. Meeting. Pp. 145-147.

Van Olst, J. C., R. F. Ford, J. M. Carlberg, and W. R. Dorband. 1976. Use of thermal effluent in culturing the American lobster. Power Plant Waste Heat Utilization in Aquaculture, Workshop 1. Publ. by PSE&G Co., Newark, NJ. Pp. 71-100.

_______________, J. M. Carlberg, and R. F. Ford. 1975. Effects of substrate type and other factors on the growth, survival, and cannibalism of juvenile Homarus americanus in mass rearing systems. Proc. World Mariculture Soc. Sixth Ann. Meeting. Pp. 261-274.

_______________, J. M. Carlberg, and R. F. Ford. 1977. A description of intensive culture systems for the American lobster, Homarus americanus, and other cannibalistic crustaceans. Proc. World Mariculture Soc. Eighth Ann. Meeting (in press).

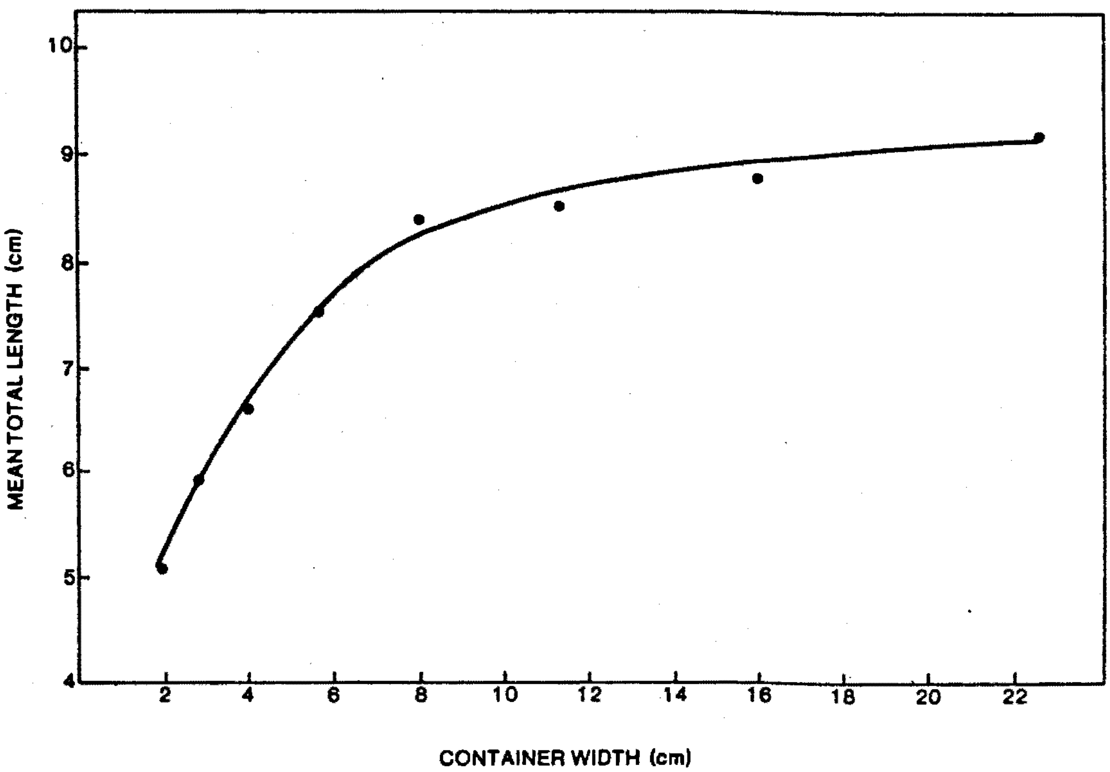

Fig. 4. Effect of eight different container sizes on mean total length of juvenile lobsters after one year of culture.