3rd Meeting of the I.C.E.S. Working Group on Mariculture, Brest, France, May 10-13, 1977.
Actes de Colloques du C.N.E.X.O., 4 : 233-245.

MAINTENANCE OF BROOD STOCK, LARVAL REARING AND NURSERY TECHNIQUES USED TO GROW *MACROBRACHIUM ROSENBERGII* IN WASTE-HEAT DISCHARGE WATERS OF AN ELECTRIC GENERATING STATION IN NEW JERSEY (U.S.A.)

by

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ABSTRACT.

Macrobrachium rosenbergii brood stock can be maintained in a fecund condition using semi-closed recirculating systems ; animals display no seasonal variation if temperature is maintained at 28°C. Prawn larvae are grown in two phases, both using semi-closed systems ; stages 1-5 are reared in 400 l tanks using Artemia nauplii as food ; stages 6-11 are transferred to 1000 l tanks and are fed synthetic food fortified with minced fish. In both systems 5 % of water is replaced daily, hence entire water mass is replaced every 20 days. Postlarvae are grown in indoor heated (27°C) nurseries at initial density of 200/m^2. Surface area of water column is augmented through use of draped netting. Prediction curves has been generated to relate juvenile size to stocking density. Juveniles are stocked in outdoor ponds at sizes ranging from 50-60 mm (eye stalk to telson). Use of nursery techniques allows for better survival of juveniles in ponds and permits harvest of commercial-size prawns (130-140 mm) in five-month growing season.

The use of waste-heat discharge waters from power stations effectively moves aquaculture laboratories 7-12° latitude towards the equator depending upon the ΔT generated. This together with nursery techniques allows for commercial production of tropical animals such as Macrobrachium rosenbergii in northern and southern temperate zones.

RESUME.

Des lots de Macrobrachium rosenbergii adultes peuvent être maintenus en état de maturité sexuelle, sans variation saisonnière, dans des unités partiellement recyclées, à une température de 28°C. Les larves sont élevées en deux phases, dans des circuits partiellement recyclés. Les stades 1 à 5 sont produits dans des bacs de 400 l, et nourris de nauplius d'Artemia. Les stades 6 à 11 sont transférés dans des bacs de 1000 l, et nourris d'un aliment composé fortifié avec dù poisson haché. Dans les 2 installations, l'eau est renouvelée à raison de 5 % par jour. Les post-larves sont élevées à l'intérieur, dans des nurseries chauffées (27°C) à une densité initiale de 200/m^2. La surface disponible dans la colonne d'eau est augmentée par des structures grillagées. Des abaques de concentration en fonction de la taille des juvéniles ont été calculées. Les juvéniles sont placés dans des bassins extérieurs à des tailles de 50 à 60 mm (pédoncule oculaire au telson). L'emploi de la nurserie permet d'obtenir une meilleure survie dans les bassins, et une récolte de crevettes commercialisables (130-140 mm) après 5 mois.

L'utilisation d'effluents thermiques de centrales électriques provoque un transfert des conditions correspondant à 7-12° de latitude à des concentrations équatoriales. En combinaison avec des techniques de nurserie adéquates, cela permet de produire des espèces tropicales comme Macrobrachium rosenbergii en zones tempérées.

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INTRODUCTION.

Fossil-fuel electric generating stations release most of the energy they derive from burning coal or oil back into the environment (GODFRIAUX *et al.*, 1975) (figure 1).

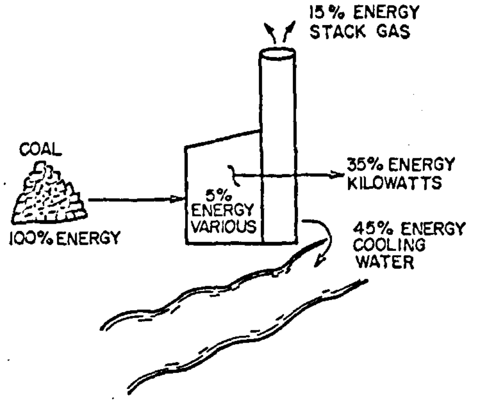

FIGURE 1 : *Schematic showing approximate energy balance in a fossil type power plant.*

Of this, the loss in discharge waters represents the greatest proportion and contributes to so-called "thermal pollution" of the environment. Waste-heat aquaculture not only offers a method of using this wasted energy but also serves to convert thermal pollution into "thermal enrichment".

The outdoor growth season in Trenton, New Jersey (latitude 40° N) of a tropical animal such as *Macrobrachium rosenbergii* would be far too short (June - August) to grow out marketable adults. The increase in temperature (ΔT) of the waste-heat discharge waters above those of Delaware River ambient (6 - 8° C) make it possible to extend the growing season to five months (May 15 - October 15). In order to grow prawns to marketable size (11 - 13 cm) in a five-month outdoor growing season, traditional methods of stocking ponds with postlarvae (FUJIMURA, 1971, 1972) had to be abandoned and indoor nursery rearing techniques had to be developed (EVANS, 1975, 1976). Ponds had to be stocked with juveniles (6 - 7 cm) in mid-May to insure harvest of adults by mid-October. Nursery grow out of juveniles also has other advantages which are discussed later in this paper.

Brood stock must be maintained in laboratory tanks in order to obtain berried females on demand. Larvae must be grown in closed systems since natural waters are too distant to employ "draw-fill" methods.

Methods of care and maintenance of brood stock and larval rearing will be described. Organization of indoor prawn nurseries will be discussed and stocking densities of early juveniles will be reported.

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MATERIALS AND METHODS.

Brood stock.

Brood stock were maintained in concrete tanks (burial vaults)painted with epoxy paint and fitted with gravel filters and immersion heaters. One type (figure 2) used baffled filters of dolomitic limestone ; the other employed an undergravel filter (figure 3) of the same material. Tanks measured 0.7 x 2.3 m and were 0.6 m deep. Five males and 15-18 females were placed in each tank which was also provided with pieces of polyvinyl chloride piping (6 cm I.D.) and draped netting to increase further the surface area for prawn habitat.

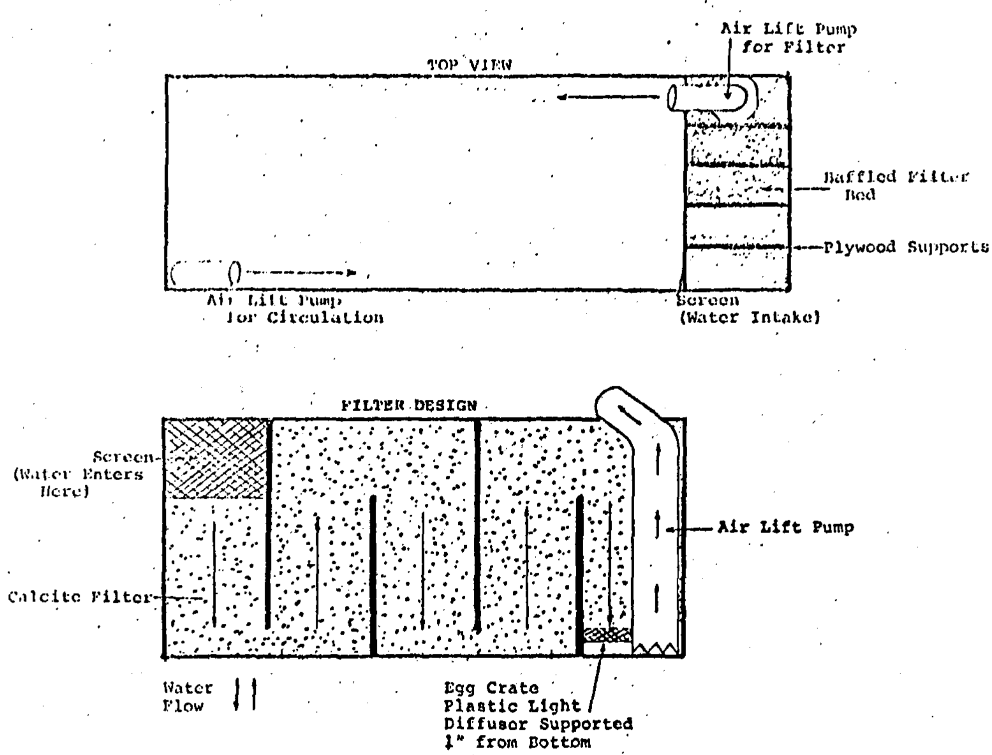

FIGURE 2 : *Brood-stock tank with baffled filter.*

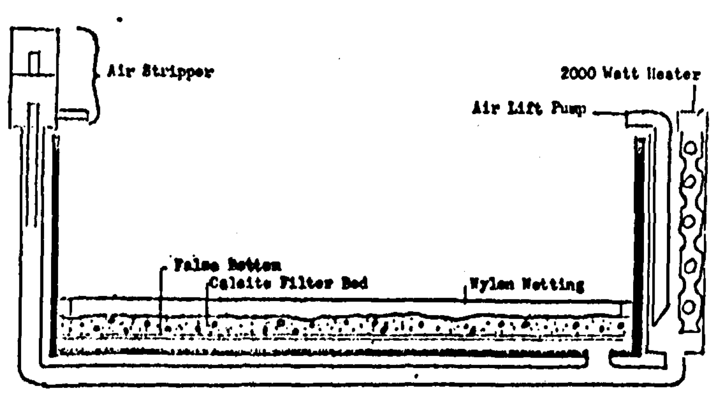

FIGURE 3 : *Brood-stock tank with undergravel filter.*

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Immersion heaters maintained tanks at 28 ± 2° C. Air-lift methods provided simultaneously for movement and aeration of water.

Animals were fed Purina Marine Mix, ration 25 at 8 % food per body weight per day ; small pieces of fish (3 - 5 g) were distributed in tank twice a week as dietary supplements.

Berried females were left in tanks until eggs began to turn grey indicating advanced embryonic development with concomitant loss of yolk. Females were then transferred to 400 liter all-glass aquaria maintained at 28° C containing brackish water (10°/₀₀). Aquaria had gravel filters at one end of the tank ; water was air lifted to far end of tank where females were kept. Fine-meshed screening (Nitex, 40-50 µm mesh size) separated females from filter ; hatched larvae were collected near screening and transferred to larval-rearing tanks.

Larvae (stages 1-5) (UNO and SOO, 1969).

Larvae were grown in :

(1) 400 l all-glass aquaria fitted with a gravel filter and protein skimmer at one end (figure 4).

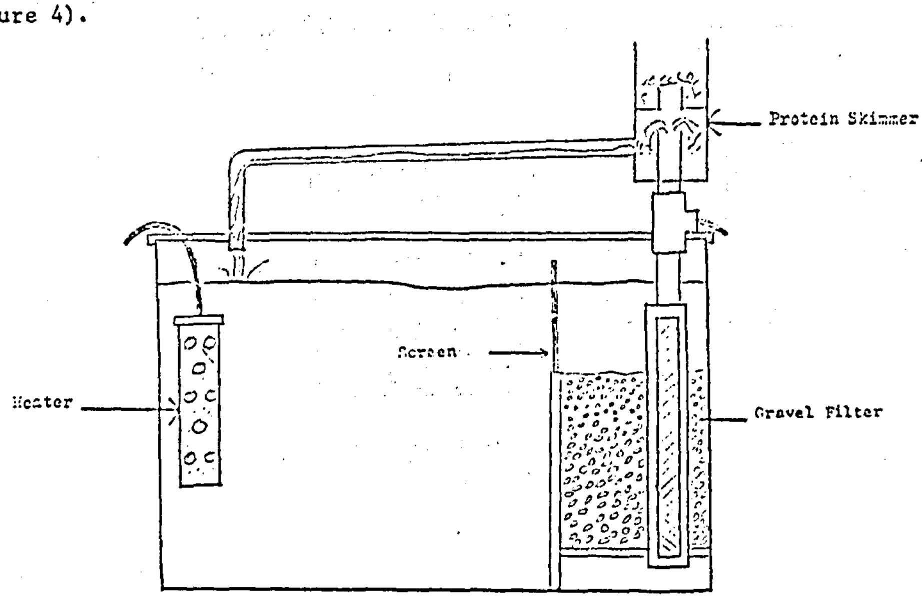

FIGURE 4 : *Larval tank using green water and protein skimmer.*

(2) 100 l conical fiberglass tanks fitted with common gravel filters (figure 5).

Immersion heaters maintained temperature at 28 ± 1° C ; salinity was adjusted to 12 - 14°/₀₀ with sea salts ("Instant Ocean" - Aquarium Systems, Inc.). Larvae were fed *Artemia* nauplii (freshly hatched).

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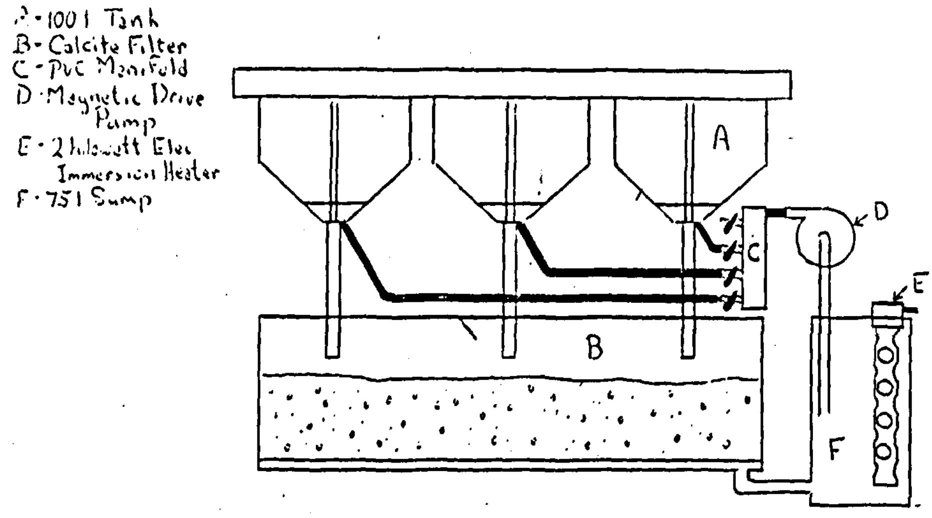

FIGURE 5 : *Early larval tanks.*

Larvae (stages 6-11).

Larvae were transferred to 1000l concrete vaults (0.7 x 2.3 m and 0.7 m deep) coated with epoxy paint. Tanks were provided with gravel filters, protein skimmers and immersion heaters similar to figure 4. Animals were fed synthetic food and finely minced fish (60-90 µm). Temperature and salinity were maintained as above (larval stages 1-5).

Postlarvae.

Newly metamorphosed postlarvae were acclimated at 5°/₀₀ salinity for three days before being transferred to fresh water. Postlarvae were grown in concrete tanks (0.7 m x 2.3 m and 0.6 m deep) fitted with vertically hanging plastic light diffusers organized into cubes 1 x 1 x 1 cm. Generating station waste-heat discharge water was pumped through tank to turn over water column 2-3 times per hour ; during winter months generating station discharge waters were heated to 28° C by a heat exchanger using natural gas as an energy source. Water was not recirculated.

Juveniles.

Juveniles were grown in same concrete vaults as postlarvae ; generating station discharge water in a once-through system flowed at same rate of exchange.

In order to test for effects of density on juvenile growth concrete vaults were subdivided by a longitudinal partition ; each subvault had its own water supply. In three tanks, each subvault received one of three substrate designs (figure 6) arranged so that each subvault was an exact replica of its counterpart. The subvaults in the fourth tank received no substrates and acted as a control. Each subvault measured 0.31 m^3 with 0.7 m^2 of bottom surface area ; those with substrates received an additional 1.1 m^2 of effective surface area for a total of 1.8 m^2. Horizontal shelves (figure 6) were composed of a netting ranging in mesh size from 0.95 cm at the top to 0.3 cm at the bottom to provide more even dispersal of food.

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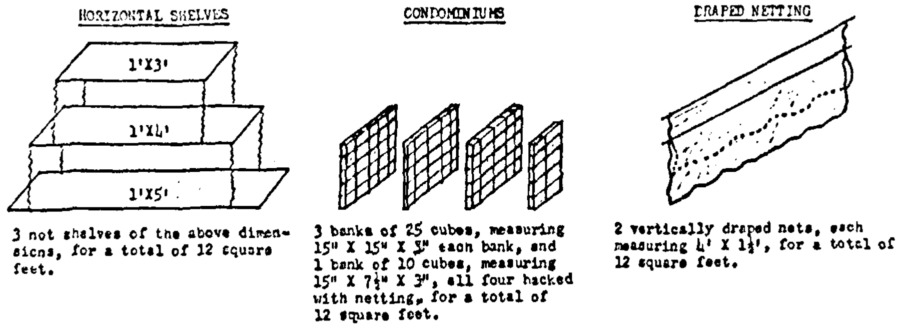

FIGURE 6 : *Three fabricated substrate designs.*

RESULTS.

Brood stock.

Incidence of berried females was variable but averaged 3-4 per week per tank for all seasons of the year.

Larvae - Postlarvae.

Larvae were grown to metamorphosis in 30-35 days. Tanks with green water (*Chlorella* sp.) showed no advantages over those without the algae. Apparently, unless very high densities of algae are used (MADDOX and MANZI, 1976) no beneficial effects on *Macrobrachium* larvae are realized. Larval densities as high as 50/l were used although the usual density was approximately 25/l. No disease symptoms were noted with the exception of a blue-green epiphytic infestation of the medial surface of the lateral carapace ; to date only unilateral infestations have been observed. The initial attachment of the alga appeared during stages 6-7 ; by stage 11 and into the postlarval stages the alga had grown so large it protruded out from the carapace as a discreet greenish mass whose bulk caused abnormal swimming behavior in infested animals. The algae has been tentatively identified as *Anabaena* sp.

Some mortalities of postlarvae have been observed during the transition from brackish to fresh water ; improper acclimatization has been ascribed as the cause.

Juveniles.

Experiments on juvenile stocking densities were begun July 24, 1975 with stocking of 100 prawns, 4-6 cm, in each subvault. This resulted in densities of 314.3/m^3 in all subvaults or 143.2 prawns/m^3 and 54.9 prawns/m^2 in the control and substrate subvaults respectively. All experiments were terminated December 20, 1975 ; results are listed in table 1. Growth, survival and density per cubic meter of water are all greater in vaults with additional substrate as compared to the control. In order to compare prawn size with survival, a plot of survival vs. prawn length was made (figure 7). A strong linear relationship between

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these points was indicated by a Correlation Coefficient (r) of -0.9 and the resultant Coefficient of Determination (r^2) of 0.81. In short, 81 % of prawn survival was directly explainable by prawn size (EVANS, 1975 a, b). A regression line fitted to this data has the equation (EVANS, 1976) : Y = 13.46 - 0.15 x (1) (figure 8).

Substrate	Replica	Initial length	Final length	Δ Length	Initial length	Final length	Δ Weight	% Survival	N°./m^2	N°./m^3
Horizontal shelves	1	54.7 mm	77.2 mm	22.5 mm	3.00 g	10.60 g	7.60 g	40	22.6	127.1
	2	54.5	77.8	23.3	3.05	11.59	8.54	37	20.5	116.5
Condominiums	1	54.3	77.0	22.7	3.23	11.02	7.79	34	18.3	105.9
	2	55.0	74.2	19.2	3.84	9.98	6.14	51	28.0	158.9
Drapped netting	1	56.0	76.3	20.3	3.66	11.02	7.36	32	17.2	98.9
	2	54.0	83.3	29.3	3.70	14.46	10.76	19	10.8	60.0
	x	54.8	77.6	22.9	3.41	11.45	8.03	36	19.4	113.0
Control	1	54.2	74.5	20.3	3.53	9.74	6.21	35	50.6	109.5
	2	54.8	74.8	20.0	3.36	10.08	6.72	21	30.1	67.0
	x	54.5	74.7	20.2	3.45	9.91	6.47	28	39.8	88.3

TABLE 1 : *Summary of substrate comparison data.*

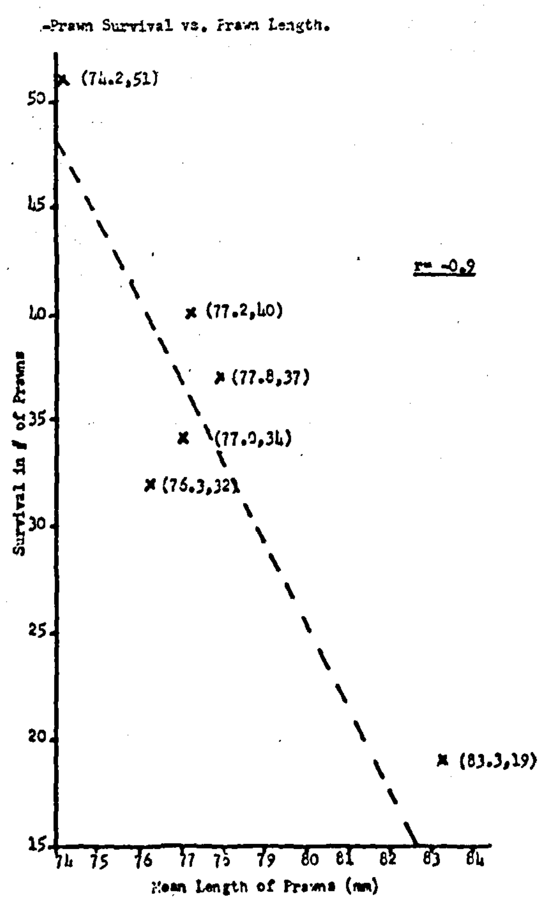

FIGURE 7 : *Prawn survival vs. prawn length.*

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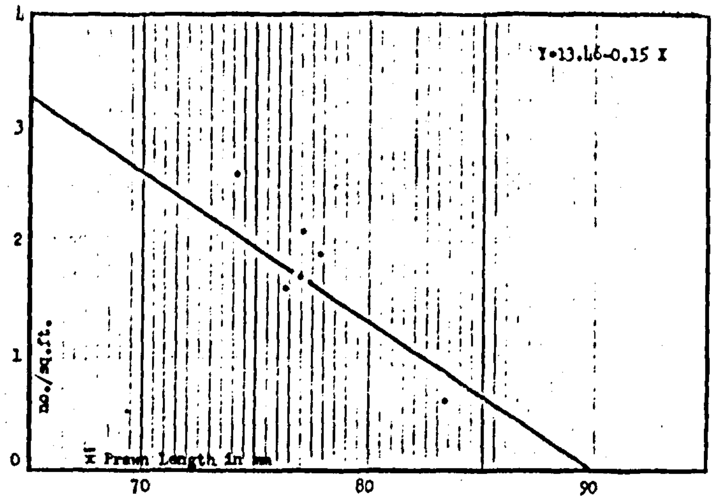

FIGURE 8 : *Prawn length-density relationship from substrate experiments.*

It would be a mistake, however, to assume that, while the data describes a straight line over its limited range; this straight-line relationship will extend over the entire range of prawn sizes. First, few if any biological relationships manifest themselves in straight lines, and, secondly, neither length nor density could realistically reach zero, as indicated by the X and Y intercepts of a straight line.

To better understand the relationship between length and density, additional length-density data were added to that used in the derivation of the above equation. Assuming the combined data (table 2) describes a curve rather than a straight line, plotting the points on a logarithmic scale should render a straight line. By converting the points to their common logarithms (table 2), the above assumption could be tested with standard linear regression analysis techniques and an equation could be derived.

X axis		Y axis	
$\bar{x}$ Length	log $\bar{x}$ Length	no./sq.ft.	log no./sq.ft.
49.6 mm	1.69548	4.7	0.67210
52.2	1.71767	4.1	0.60278
46.8	1.67025	4.9	0.69020
46.9	1.67117	6.6	0.81954
44.9	1.65225	6.7	0.82607
45.2	1.65514	8.8	0.94448
83.2	1.92012	1.5	0.17609
86.1	1.93500	1.1	0.04139
93.1	1.96895	1.0	0.00000
77.2	1.88762	2.1	0.32222
77.8	1.89098	1.9	0.27875
74.5	1.87216	4.7	0.67210
74.8	1.87390	2.8	0.44716
77.0	1.88649	1.7	0.23045
74.2	1.87040	2.6	0.41497
76.3	1.88252	1.6	0.20412
83.3	1.92065	1.0	0.00000
64.6	1.81023	2.7	0.43136
58.0	1.76343	5.6	0.74819
55.4	1.74351	5.7	0.75587
58.0	1.76343	5.7	0.75587
59.5	1.77452	5.1	0.70757
55.0	1.74036	3.8	0.57820
58.0	1.76343	4.2	0.62325
59.2	1.77232	5.2	0.71600

TABLE 2 : *Data used for derivation of prawn density vs. mean prawn length prediction curve.*

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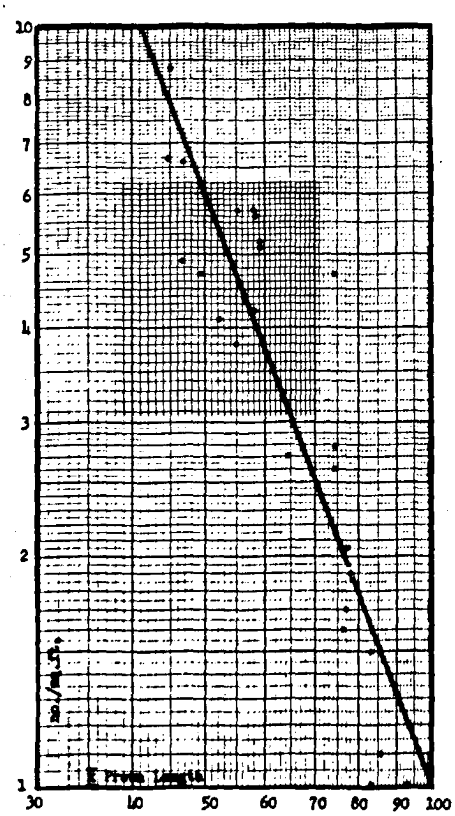
Analysis of variance shows significant influence on density vs. length at the 99 % probability level and the resulting regression line (EVANS, 1976) : Log Y = 5.17480 - 2.58769 log x (2) has a Correlation Coefficient of -0.9 and a Coefficient of Determination of 0.81, again indication that 81 % of the variation in density is directly attributable to prawn length.

Numerical values of X (length) are converted to common logarithms and equation (2) is solved for log values of Y (density) ; antilogs determine the numerical values of Y to form a series of coordinates which describe the straight line in figure 9. This straight line on logarithmic scales is actually a curve on numerical scales ; figure 10 depicts the transposition of the line and points from figure 9 on to numerical scales.



<u>FIGURE 9</u> : *Prawn length-density relationship on lagarithmic scale.*

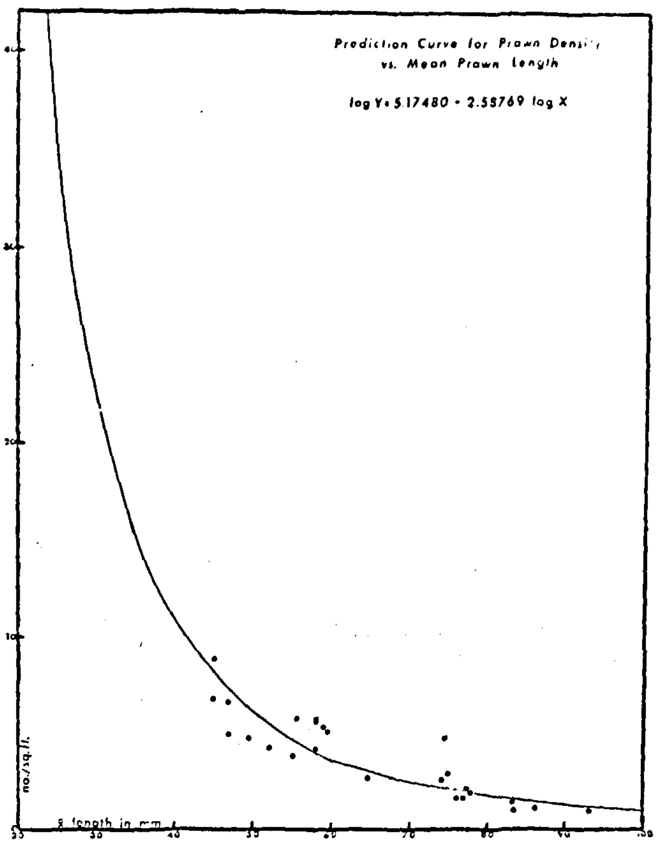


FIGURE 10 : *Prediction curve for prawn density vs. mean prawn length.*

DISCUSSION.

Aquaculture is in its infancy and is at the stage where agriculture was 10,000 years ago. However, giant strides have been made in the past decade on a world-wide basis (BARDACH, RYTHER and McLARNEY, 1972).

The use of waste-heat discharge waters from electric generating stations have been the subject of theoretical speculations (COUNTANT, 1970 ; YEE, 1971 ; YAROSH *et al.*, 1972) as well as pratical applications (GUERRA *et al.*, 1975 ; GUERRA *et al.*, 1975). The use of waste-heat discharge waters of electric generating stations effectively moves the aquaculture site 13° - 20° latitude towards the equator depending upon the ΔT of the station. This makes it possible to raise sub-tropical and tropical species in northern and southern temperate zones.

Macrobrachium aquaculture has gained widespread popularity (GOODWIN and HANSON, 1975) and although originally cultured only in tropical countries, it has now spread well into the northern temperate zone (GUERRA *et al.*, 1975 ; SANDIFER and SMITH, 1975, 1977). However, even with the use of waste-heat discharge waters from electric generating stations, outdoor growing seasons are less than six months. Thus, new techniques of rearing postlarvae and juveniles in indoor heated nurseries preliminary to pond stocking have evolved (EBLE, 1975, 1976 ;

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EVANS, 1975, 1976 ; SANDIFER and SMITH, 1977). Juveniles are stocked in outdoor ponds at sizes ranging from 4-7 cm and harvested as adults (11-13 cm) five months later. Elaborate designs to increase effective surface area of tank volumes have been worked out (EVANS, 1975, 1976 ; SMITH and SANDIFER, 1975) and prediction curves for maximum postlarval and juvenile stocking have been derived (EVANS, 1976 ; SANDIFER and SMITH, 1977).

It is predicted that *Macrobrachium* aquaculture industries throughout the world (even in the tropics) will use nursery grow-out techniques within five years ; the reasons for this are manifold :

1- juveniles have an increased chance of survival in outdoor ponds ;

2- slow growing postlarvae can be artificially selected against, thus only fastest growing animals are stocked in ponds ;

3- juvenile nurseries can be managed better than ponds ;

4- outdoor growing seasons can be shortened by 40-50 %.

CONCLUSIONS.

Macrobrachium rosenbergii brood stock can be maintained in small concrete vaults using closed cycle techniques. Animals thrive and breed normally ; average fecundity if 3-4 berried females per week per tank for all seasons of the year.

Larvae are raised in small (100 l and 400 l) tanks from stages 1-5 using closed cycle techniques and *Artemia* nauplii as food. Stages 6-11 are grown in large (1000 l) tanks using closed cycle techniques with synthetic food fortified with minced fish.

Juveniles must be grown in indoor heated nurseries preliminary to pond stocking. Surface area of water column is augmented through use of fabricated substrates, prediction curves have been generated to relate juvenile size to stocking density.

The use of waste-heat discharge waters from power stations effectively moves aquaculture laboratories 7-12° latitude towards the equator depending upon the ΔT generated. This together with nursery grow out techniques, allows for commercial production of tropical animals such as *Macrobrachium rosenbergii* in northern and southern temperate zones.

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HOMARDS ET CRABES

LOBSTERS AND CRABS